CERTIFICATE OF APPROVAL

Development of Boiling Liquid Expanding Vapor Explosion (BLEVE) Model for Process Plant Design

by

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgement, and that the original contained herein have not been undertaken or done by unspecified sources or persons.

(MOHAMAD IRWAN ABDUL)

ABSTRACT

Boiling Liquid Expanding Vapor Explosion (BLEVE) was dangerous and can cause humongous loss for the process plant. Reid (1976) defined BLEVEs as the sudden loss of containment of a liquid that is at a superheated temperature for atmospheric conditions. There are a lot of commercialized tools in estimating the effects of BLEVE but very complicated and not user friendly. Development of model from Microsoft Excel in estimating the BLEVE effects was a main objective in this project.

In this project, a process in MLNG Malaysia was utilized as one of the case study. Stabilizer C-2502 was utilized as case study in this project. The feed to Stabilizer- 2502, consist of the bottom form the Demethanizer and any propane, which is being re-processed from the liquefaction unit. In this project, HYSYS simulator acted as "live" thermodynamic database to be extracted to Microsoft Excel for effect estimation.

The first effect is overpressure or blast effect. In this case study the maximum overpressure due to distance is 0.87 psi which the damage is partial demolition of houses. The second effect is thermal radiation. The result that obtained is in term radiation dose. The maximum radiation dose is 721.171 kJ/m^2. This will cause third -degree burns (99% fatal).

In this Final Year Project, the result from this BLEVE model is compared to the result from SAFETI Software. The SAFETI Software has being established for many years and well known in the process industries. This is to validate the result the obtained from BLEVE model.

The main objectives were accomplished. The desired data from HYSYS is extracted to ME interface to performs the calculation and effect estimation. Further development of this project is commercially advisable.

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TABLE OF CONTENTS

CERTIFICATION OF APPROVAL			**I**
CERTIFICATION OF ORIGINALITY			**II**
ABSTRACT			**III**
ACKNOWLEDGEMENT			**IV**
TABLE OF CONTENTS			**V**
LIST OF FIGURE			**VII**
LIST OF TABLE			**IX**
ABBREVIATIONS			**X**
NOMENCLATURE			**XI**
CHAPTER 1:	**INTRODUCTION**		**1**
	1.1	Background of Study	1
	1.2	Problem Statement	2
	1.3	Objectives	3
	1.4	Scope of Study	4
CHAPTER 2:	**LITERATURE REVIEW**		**5**
	2.1	Inherent Safety	5
	2.2	Quantitative Risk Assessment (QRA)	7
	2.3	Major Hazards in Chemical Process Industries	8
	2.4	Explosion	9
	2.5	Boiling Liquid Expanding Vapor Explosion (BLEVE)	12
	2.6	Available Simulation Tools	13
	2.7	Concluding Remarks	14

CHAPTER 3:	**THEORY**	**15**
	3.1 Case Study..	15
	3.2 BLEVE Effects Estimation Method..........................	17
	3.2.1 BLEVE Limitation......................................	17
	3.2.2 BLEVE Blast Effect....................................	17
	3.2.3 BLEVE Thermal radiation Effect......................	20
	3.2.4 BLEVE Missile Projectile Effect......................	24
	3.3 Concluding Remarks..	25
CHAPTER 4:	**METHODOLOGY/PROJECT WORK**	**26**
	4.1 Procedure Identification..	26
	4.2 Case Study..	27
	4.3 Overheated Vessel..	27
	4.4 Range of BLEVE Limit...	27
	4.5 Boling Liquid Expansion Vapor Explosion (BLEVE)......	27
	4.6 Mathematical Calculation in Microsoft Excel................	27
	4.7 Summarize All the Effects.....................................	28
	4.8 Reconsider Process Design....................................	28
CHAPTER 5:	**RESULT AND DISCUSSION**	**29**
	5.1 Case Study..	29
	5.2 BLEVE Limitation..	30
	5.2.1 BLEVE Limitation Calculation..........................	30
	5.2.2 BLEVE Limitation Discussion...........................	31
	5.3 BLEVE Blast Effect..	31
	5.3.1 BLEVE Blast Effect Calculation........................	31
	5.3.2 BLEVE Blast Effect Discussion.........................	32
	5.4 BLEVE Thermal Radiation Effect.............................	35
	5.4.1 BLEVE Thermal Radiation Effect Calculation.........	35
	5.4.2 BLEVE Thermal Radiation Effect Discussion.........	35

5.5 Concluding Remarks... 38

CHAPTER 6: CONCLUSION **39**

6.0 Conclusion.. 39

CHAPTER 7: PROBLEMS AND RECOMMENDATIONS **40**

7.1 Problems Encountered.. 40

7.2 Recommendation.. 40

REFERENCE **42**

APPENDIX A .... **XIII**

APPENDIX B .... **XIV**

APPENDIX C .... **XVII**

APPENDIX D **XX1**

APPENDIX E .... **XXIV**

LIST OF FIGURES

CHAPTER 1.0

Figure 1.1 Causalities of incidents in Malaysia at year 1999.............................2

CHAPTER 2.0

Figure 2.1 Reaction and pressure fronts propagating through a pipe.....................9

Figure 2.2 Average dollar loss to types of major hazards in hydrocarbon industries, (J&H Marsh and McLennan Consulting, 1998)..................................11

Figure 2.3 Frequency of event of 100 large property damage losses in hydrocarbon processing industry from 1966 to 1996, (J&H Marsh and McLennan Consulting, 1998)..11

Figure 2.4 Causalities in incidents world wide (DOSH Malaysia, 2001)...............12

CHAPTER 3.0

Figure 3.1 Process Flow Diagram of Case Study..16

Figure 3.2 Correlation between overpressure and scaled distance SI units (Joseph F. Louvar, 1990)...19

Figure 3.3 Assumed Orientation of a Ground level Target to the Fireball Surface (CCPS, AIChE, 2000)..23

CHAPTER 4.0

Figure 4.1 Methodology of project..26

CHAPTER 5.0

Figure 5.1 Simulation of Stabilizer C-2502..29

Figure 5.2 Graph Overpressure, Psi versus Radius, m for BLEVE Explosion......33

Figure 5.3 Graph BLEVE Overpressure versus Distance Downwind. (SAFETI Software)...33

Figure 5.4 Graph Thermal Dose Radiations versus Distance Radiation.............36

Figure 5.5 Graph Radiation Level versus Distance Downwind. (SAFETI Software)...37

APPENDIX A

Figure A.1 Gantt chart...XIII

APPENDIX B

Figure B.1 Correlation between overpressure and scaled distance SI units (Joseph F. Louvar, 1990)..XIV

APPENDIX C

Figure C.1 Process Flow Diagram of Case Study (Established LNG Plant, 2003)...XVII

Figure C.2 HYSYS simulation (Steady –State) of Case Study.........................XIX

Figure C.3 Simulation of Stabilizer C-2502...XX

APPENDIX D

Figure D.1 Shock Wave Parameter for Spherical TNT Explosion on Surface at Sea Level (AiChe, 2000)..XXI

Figure D.2 The Sachs Scale Side-On Overpressure and Positive Phase Duration are provided as A Function of the Sachs Scale Distance (AiChe, 2000)...XXII

Figure D.3 Lower Heat Combustion Data for Explosion Calculation. (J .M Ssantamaria Ramiro, 1990)..XXIII

LIST OF TABLES

CHAPTER 3.0

Table 3.1 Damage produced by overpressure (Joseph F. Louvar, 1990)..............20

Table 3.2 Thermal Dose Injury Criteria (Prugh, 1994)..................................24

CHAPTER 5.0

Table 5.1 Thermodynamic Data for Propane Case Study (Perry Chemical Engineers' Handbook 1998)..30

Table 5.2 BLEVE Limitation Data and Calculation.....................................30

Table 5.3 Change in Internal Energy and Work Done by the Explosion.............32

Table 5.4 Scaling and Explosion Parameter..32

Table 5.5 The Overpressure and Damage With Respect to the Explosion Parameter...33

Table 5.6 Result for BLEVE Thermal Radiation Effect Calculation...................35

Table 5.7 The Thermal Dose Radiation and Injury Description with Respect to the Radiation Parameter..36

APPENDIX B

Table B.1 Thermal Dose Injury Criteria (Prugh, 1994)................................XIV

Table B.2 Damage produced by overpressure (Joseph F. Louvar, 1990)............XV

Table B.3 Saturated Vapor Pressure of Water as a Function of Temperature (AiChe, 1998)...XV

APPENDIX C

Table C.1 Plant Parameters (MLNG Malaysia, 2003)...............................XVII

ABBREVIATIONS

AIChE	*American Institution of Chemical Engineering*
ALARP	*As Low As Reasonably Practicable*
BLEVE	*Boiling Liquid Expanding Vapor Explosion*
CCPS	*Center for Chemical Process Safety*
CPI	*Chemical Process Industries*
CVCE	*Confined Vapor Cloud Explosion*
DOSH	*Department Occupational and Health*
HEMP	*Hazards and Effects Management Process*
LPG	*Liquefied Petroleum Gas*
ME	*Microsoft Excel*
QRA	*Quantitative Risk Assessment*
TNT	*TriNitroToluene*
UDM	*Unified Dispersion Model*
UVCE	*Unconfined Vapor Cloud Explosion*

NOMENCLATURE

$D(t)$	*Fireball diameter during the growth phase*	meter
D_{max}	*Maximum fireball diameter*	meter
Es	*Surface emitted flux*	kW/m^2
E_{max}	*Maximum surface emitted thermal flux*	kW/m^2
f	*Radiant heat fraction*	
F	*Maximum geometric factor*	
H_{fb}	*Height of the center of the fireball*	meter
H_c	*Net heat of combustion of the flammable material*	kJ/kg
h	*Enthalpy*	Btu/lb
I_{th}	*Thermal flux*	kW/m^2
I_{dose}	*Thermal dose*	kW/m^2
$m_{f,I}$	*Liquid masses, respectively , at state i,*	lb
$m_{g,I}$	*Vapor masses, respectively , at state i,*	lb
m_{TNT}	*Equivalent mass of TNT*	kgTNT
M_{fb}	*Mass of released flammable material in the fireball*	kg
P_c	*Critical pressure*	bar
P	*Pressure*	bar
P_B	*Burst pressure of the vessel*	MPa
P_V	*Saturated vapor pressure of water at the ambient temperature*	Pa
R_{flash}	*Initial ground flash radius*	meter
R	*Fractional relative humidity*	
s	*Entropy*	Btu/lbR
T_{sl}	*Superheat temperature limit*	K
T_c	*Critical temperature*	K
T	*Temperature*	K
t_d	*Duration of combustion*	sec
U	*Internal energy*	Btu

W	*Work done*	joule
x_f	*Fraction of the initial liquid mass that flashed to vapor*	
x_g	*Fraction of initial vapor mass do not condense in the explosion*	
Z	*Scaled range*	

Greek Letter

τ	*Atmospheric trasnmissivity*

CHAPTER 1

1.0 INTRODUCTION

1.1 Background of study

Safety and loss prevention is an important aspect in plant design processes. Design and operating companies spend large amount of money and expertise to ensure safety is included from the beginning of design right up to operations. In design stage, risk assessments are carried out for internal design uses as well as to oblige by government regulations. Some authorities such as United State Environmental Protection Agency (USEPA) commit companies to perform risk assessment based on worst –case scenarios.

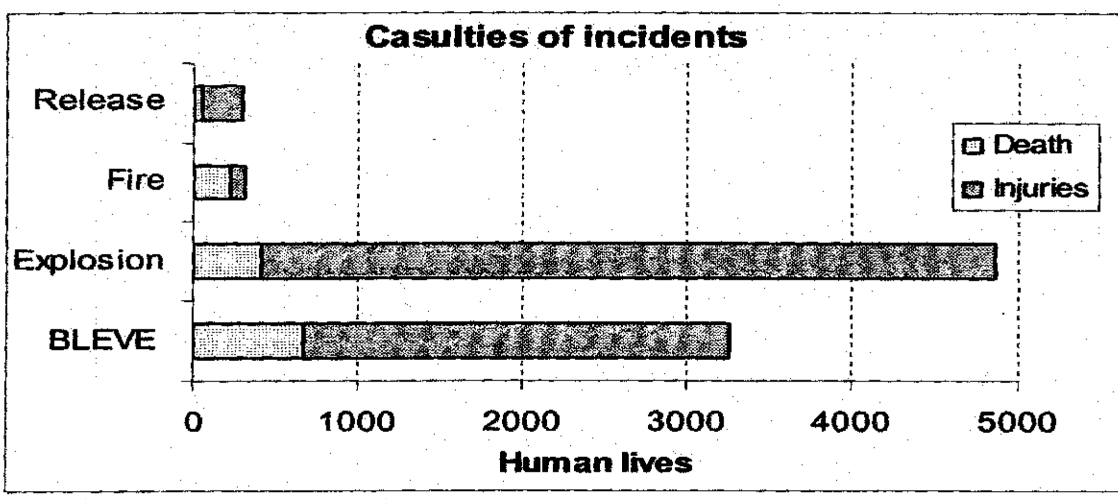
In Malaysia, chemical and petrochemical industries are required to perform risk assessment as part of the project approval process (Environmental Quality Act 1974). All the process owners are also required to submit risk and consequence assessment to Department of Occupational Safety and Health (DOSH) (Control of Industrial Major Accidents and Hazards (CIMAH) Regulation 1996 Schedule 6).

A reliability and safety assessment method is very important in the process industries. The objectives are to improve the safety and availability of new and existing plant. The Quantitative Risk Assessment (QRA) is to estimate the potential risk level of the plant design and it was done at the end of the design stage. With the new approach, the QRA can be done simultaneous in the design stage.

1.2 Problem statement

The risk assessment analysis or the QRA of process plant is done when the process design stage is almost completed. The process designer is often lack of information about risk levels and consequence that may result in diversion of their process condition. One of the consequences is Boiling Liquid Expanding Vapor Explosion (BLEVE) that could occur if enough ignition source available near to the process equipment. Therefore, it is vital to estimate the risk created from BLEVE during design stage, as this will promote the development of inherently safer plant at earlier stage.

The second dangerous and destructive accidents in the chemical process industries are BLEVE (DOSH, 1999).



Source: DOSH, 1999

Figure 1.1: Causalities of incidents in Malaysia at year 1999

BLEVE have increased in number due to an increase in inventories of flammable materials in chemical process plant and operation at more severe conditions. Any process containing quantities of liquefied gases, volatile superheated liquid, or high- pressure and temperature gases is considered good candidates for a BLEVE.

The model is important for process designer to study on the risk assessment analysis of process in plant. All the data, calculation, discussion and simulation in this project will be used as a parameter for process designer to simulate the possibility of BLEVE to happen and its effects in the plant. Besides that, the data and the result obtained from the BLEVE model will be used to compare with the data obtained from other BLEVE tools/ simulator.

Typical risk assessment software such as BLEVE incident simulator (BIS), Atmospheric Dispersion of Reactive Agent (ADORA) has been specifically designed with the safety processing, safety analysis, and safety control. However these softwares are too general in terms of estimating the BLEVE effects in the process plant. These softwares also are too complicated with their interface and only for advanced users.

Process simulator like HYSYS is widely used in process design. This simulator is bale to provide designers the optimized condition of the process, reflect any changes in conditions immediately. Advanced features can help process owners calculate the process economics. This simulator is useful in determining which route to choose and develop. In later stage, they can be used as training tool. However, current process simulator is not equipped with tool to determined risk and effects related to the major equipments. Development of such tool would allow inherent safety features be incorporated into design.

1.3 Objectives

The main objective of the project is to create a tool/simulator to estimate the risk created from BLEVE during design stage. There also some other objectives that needs to be achieved through this project; there are:-

a. To develop BLEVE models in Microsoft Excel Application
b. To test the models with established data for BLEVE risk
c. To apply the models in LNG plant as case study in HYSYS to validate the tool.

1.4 Scope of study

In order to achieve the objectives, the scopes have been defined and used as guidelines.

There are many major hazards in the chemical process industries, like fire, explosion, toxic release and vapor cloud explosion. The research focused on Boiling Liquid Expanding Vapor Explosion (BLEVE) as this hazard causes the second largest amount of monetary losses and resulted in highest number of casualties.

There are many methods available to estimate risk due to explosion. In this research, the TNT Equivalent Method is used. These equations and correlations are widely used in commercially available software and widely acceptable by industries and government agencies.

A failure of either equipment or operational standards could, in some cases, result in an explosion which could take one or many forms. For example the explosive failure of pressure vessel due to over pressurization or a vapor cloud explosion (VCE) following an ignited release of flammable gases. The research focused on studying the effect of external fire exposure (i.e, pool fire under the vessel) that will cause BLEVE effects.

The BLEVE tool/simulator would be applied in the real case study such as in LNG plant. Microsoft EXCEL is used as development platform for the risk estimation tool. This case study was simulated by using process simulator, HYSYS. In this project, HYSYS simulator acted as "live" thermodynamic database. Based on the case study (steady state) simulation, the needed composition and properties of the process can be obtained and then extracted to Microsoft Excel for effect estimation.

This project will go deeply in the Boiling Liquid Expanding Vapor Explosion (BLEVE) effects. Some of the effects will be studied such as the thermal radiation, the missile projectile and estimation of overpressure. Generally, all these effects will be discussed further in literature review section. To simplify the study scope, this project is expected to be able to explain some of the critical effects of the BLEVE in the process plant.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Inherent Safety

Inherent means "built-in". Safety feature is an important feature in everyday life including chemical process industries. Inherent safety can thus be defined as safety features that are built-in to a process from early design stages and through out its life cycle.

Inherent safety has become and important aspect and is deemed as the best method to design a plant safe for operation with no harm to the environment, health and also equipments. Traditionally, safety features are more of "reactive" countermeasure rather than a "proactive" means to prevent accident. Inherent safety approach is also the opposite of Traditional Safety approach (also known as Extrinsic Safety). The Traditional Safety approach aims to reduce risk of a process by adding protective barriers to control hazards. Inherent Safety on the other hand aims to reduce or eliminate the hazards by modifying the design of the plant itself. Inherent Safety is a proactive approach for hazard or risk management during process plant design and operation.

Inherent Safety sometimes referred to as "primary prevention" is an approach to chemical accidents that is opposite of "secondary accident prevention" and mitigation. Inherent Safety is helpful also for pollution prevention. This approach to safety is based on the use of technologies and chemicals that reduce or eliminate the possibility of an accident.

On the other hand, Traditional Safety relies on the reduction and migration of the consequences of an accident. This last approach alone is unable to avoid or reduce the risk of serious accident (Zwetsloot G. and Askounes-Ashford, 1999).

While Traditional Safety approach can be very efficient and useful, it presents some disadvantages too. The initial cost of building a plant could be lower, compared with inherent safer options, however the installation of safety barriers represent additional expenses.

The barriers themselves require expensive maintenance (Lutz, W.K, 1997) and they can suffer partial or complete dangerous failures (undetected failure). Since the original hazards are still present, accidents can occurs and their consequences could be worse by generous –failure mode of the barrier. Because the social, environmental and economical cost derived from every accident is not taken in the short term economical analysis of a process, the initial lower cost of the plant is usually untrue.

Principles defining Inherent Safety were formalized by Trevor Kletz (1991) and summarized below:

a. Intensification - Reduction of the inventoried of hazardous materials.
b. Substitution - Change or hazardous chemicals substances are less hazardous chemicals.
c. Attenuation - Reduction of the volumes of hazardous materials required in the process. Reduction of operation hazards by changing the processing conditions to lower temperature, pressure or flows.
d. Limitation of Effects – The facilities must be designed in order to minimize effects of the hazardous chemicals or energies releases.
e. Simplification - Avoidance of complexities such as multi-product or multi-unit operations, or congested pipe or unit settings.
f. Error Tolerance – Making equipment robust, processes that can bear upsets, reactors able to withstand unwanted reactions, ect.

In this research, the attenuation principle is used, where we try to reduce the operation hazards by changing the processing conditions to lower temperature. It is because in BLEVE, the process temperature is critical.

2.2 Quantitative Risk Assessment (QRA)

Many tools are available for Hazards and Effects Management Process (HEMP) to assess and control on industrial risk. These tools are not mutually exclusive and each of the tools has its advantages and appropriate applications. Among the HEMP tools, Quantitative Risk Assessment (QRA) is a powerful decision making tool which can assist in the selection of acceptable solutions to safety problems. This technique can be defined as the formal and systematic approach to identifying hazards, potentially hazardous events and estimating likelihood and consequences to people, environment and assets, of incidents developing form these events (Shell International Exploration,1995). The total process of risk analysis interpretation of results and recommendations of corrective actions is usually called "Risk Assessment".

Over last decade, QRA has gained a wide acceptance as powerful tool to identify and assess the significant sources of risk and evaluate alternative risk control measures in chemical process industries. QRA is also considered a valuable tool indecision making process, to communicate among the expert involved, to quantify options and to combine these effectively with available statistical data. A properly preformed risk analysis documents the best knowledge of the company's technical experts. Application of QRA has contributed not only to increased safety but also improved cost effectiveness in many areas.

Quantitative Risk Assessment (QRA) should only be used with proper intentions. Like any tool misuse of QRA can bring about undesirable incidents. QRA should be used:

a. To reduce risk rather than to prove acceptability
b. To minimize risk to as low as reasonably practicable (ALARP) is required.
c. To represent reality rather than force fitting into a rigid model.
d. To compare like to like

Quantitative Risk Assessment (QRA) will only be successfully carried out if:

a. QRA specialists work and communicates with others in the project
b. Proper data handling is observed i.e. selecting and suing the most reliable and applicable data.
c. Appropriate level of detail is used

2.3 Major Hazards in Chemical Process Industries

In Chemical Process Industries (CPI), safety plays a very important role in ensuring that there will be no damage to the environment and the process plants pose no danger to the people working in the plant. Major hazards include release of hazardous materials, fire and explosion.

Major accidents in chemical industry have occurred worldwide. Increasing industrialization after the Second World War also led to a significant increase of accidents involving dangerous substances. In Europe, in the 1970's two major accidents in particular prompted the adoption of legislation aimed at the prevention and control of such accidents.

The Flixborough accident in the United Kingdom in 1974 was a particularly spectacular example. A huge explosion and fire resulted in 28 fatalities, personal injury both on and off-side. It also had a domino effect on other industrial activity in the area, causing the loss of coolant at nearby steel works, which could have led to a further serious accident.

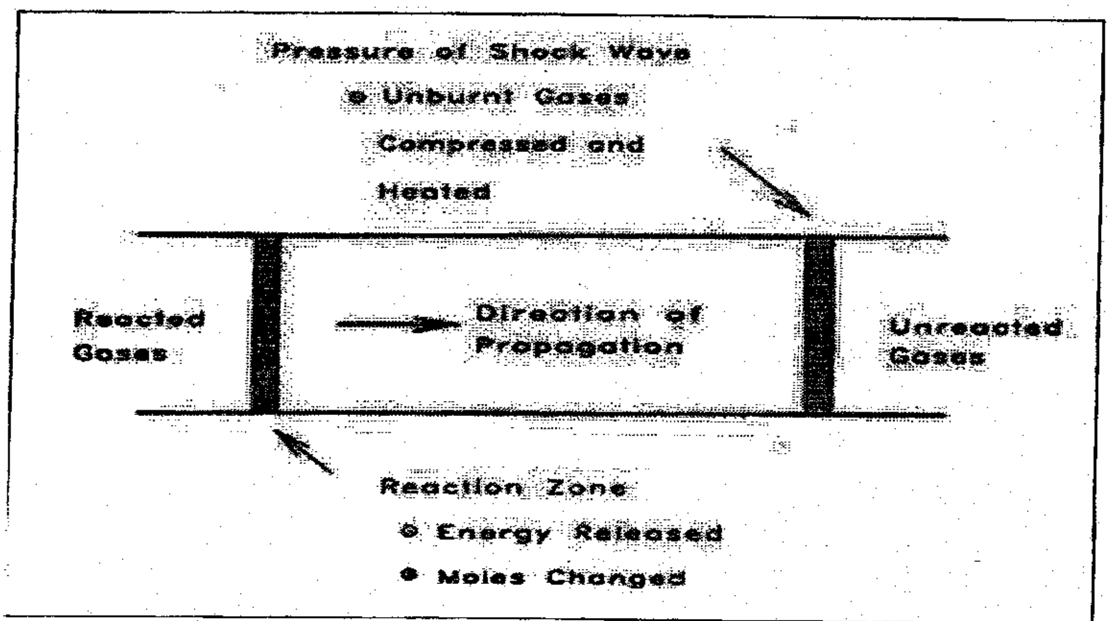
The Seveso accident happened in 1976 at a chemical plant manufacturing pesticides and herbicides. A dense vapor cloud containing tetrachlorodibenzoparadioxin (TCDD) was released from a reactor, used for the production of trichlorofenol. Commonly known as dioxin, this was a poisonous and carcinogenic by-product of an uncontrolled exothermic reaction. More than 600 people had to be evacuated from their homes and as many as 2000 were treated for dioxin poisoning.

Another notable accident was at the Union Carbide factory in Bhopal, India (1984) where a leak of methyl isocyanate caused more than 2500 fatalities.

2.4 Explosion

Explosion behavior depends on a large number of parameters. Those parameters are ambient temperature, ambient pressure, composition of explosive material, physical properties of explosive material, nature of ignition source , amount of combustible material and rate at which combustible is released (Joseph F. Louvar, 1990).

Explosion are either detonations or deflagrations, the differences depends on the speed of shock wave emanating form the explosion. Both detonation and deflagrations can be illustrated by using a long pipe which a combustible mixture is placed as Figure 2.1 below (Joseph F. Louvar, 1990).



Source: Joseph F. Louvar, 1990

Figure 2.1: Reaction and pressure fronts propagating through a pipe

A small spark, flame or other ignition source initiates the reaction at one end of the pipe. After ignition, a flame or reaction moves down the pipe. In front of the flame front is a pressure or shock wave as shown in Figure 2.1. If the pressure wave move faster than the speed of sound in the un-reacted medium, the explosion is detonation, if it moves at a speed of sound, it is a deflagration.

There are several mechanisms leadings to explosive detonation (Joseph F. Louvar, 1990). The essential ingredient is that the energy must be released in very short time within a very small volume to produce a significant initial pressure shock wave; two mechanisms have been proposed to describe such an event. For the first mechanism is called the thermal mechanism. The gas temperature increase by reaction, leading to self-acceleration of the reaction rate. The second mechanism is called the chain branching mechanism. Reactive free radicals are rapidly increased in numbers by elementary reaction. Both of these mechanisms can account for explosive behavior. In reality both are bound to occur.

A deflagration can also evolve into a detonation. This is particularly common in pipes but unlikely in vessel or open spaces. In a piping system, energy from a deflagration can feed forward to the pressure wave, resulting in an increase in the adiabatic pressure rise. The pressure builds and results in a full detonation.

Explosion includes Vapor Cloud Explosion, Boiling Liquid Expanding Vapor Explosion (BLEVE) and Mechanical Explosion. J&H Marsh and McLennan (1998) had shown that explosion and vapor cloud explosion caused large losses in monetary terms. Figure 2.2 and 2.3 shows average million dollar loss in 100 large property damage losses in hydrocarbon processing industry due to different types of event from 1966 to 1996.

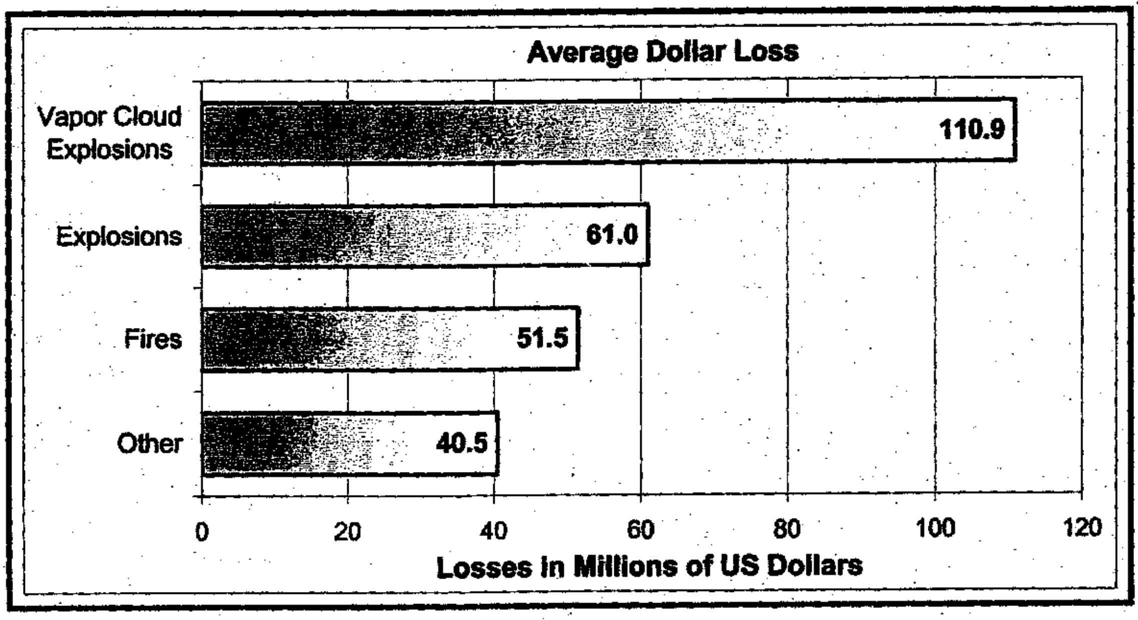


Figure 2.2: Average dollar loss to types of major hazards in hydrocarbon industries, (J&H Marsh and McLennan Consulting, 1998)

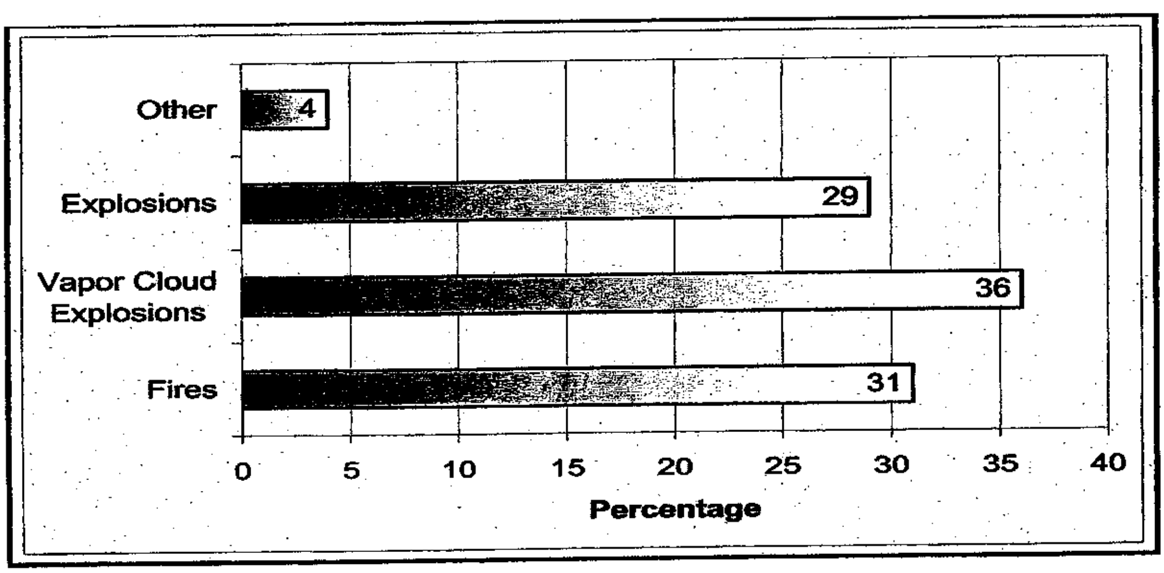


Figure 2.3: Frequency of event of 100 large property damage losses in hydrocarbon processing industry from 1966 to 1996, (J&H Marsh and McLennan Consulting, 1998)

Apart form causing large monetary losses, these incidents also caused large numbers of casualties. Owing to its damaging blast waves, explosions caused the higher number of death and injuries. This is reflected in Figure 2.4.

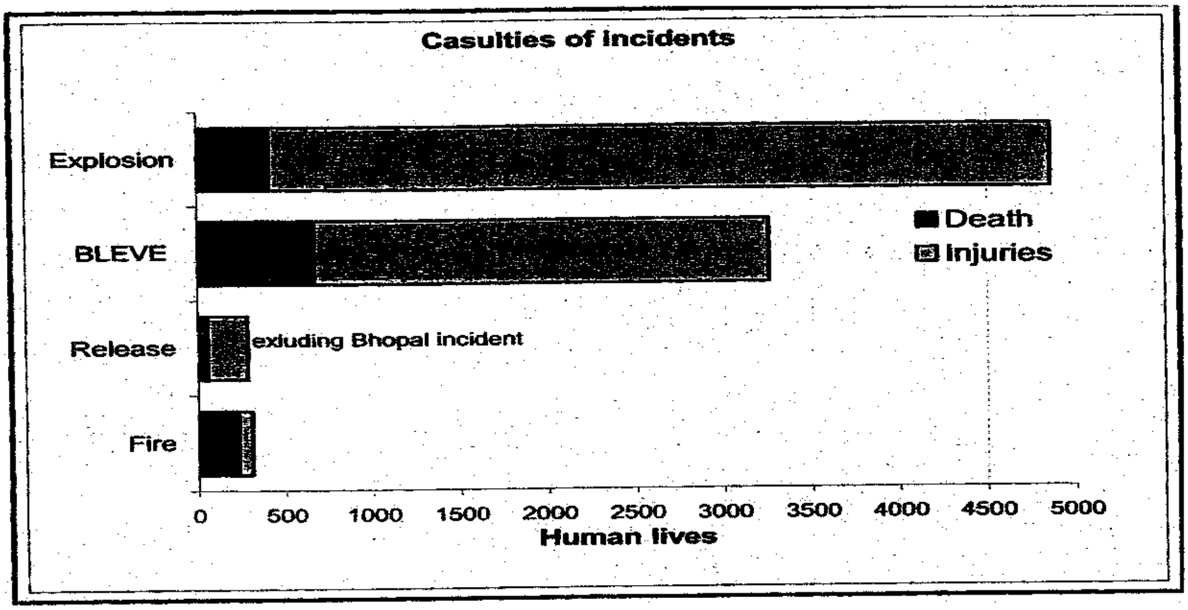


Figure 2.4: Causalities in incidents world wide (DOSH Malaysia, 2001)

2.5 Boiling Liquid Expanding Vapor Explosion (BLEVE)

A boiling liquid expanding vapor explosion (BLEVE) is a special type of accident that can release large quantities of materials. If the materials are flammable a Vapor Cloud Explosion (VCE) might result; if toxic, a large area might be subjected to toxic materials. For either situation, the energy release by the BLEVE process itself can result in considerable damage.

Boiling liquid expanding vapor explosions were defined by Walls (1979), one of those who first proposed the acronym BLEVE, as a failure of a major container into two or more pieces occurring at a moment when the container is at a temperature above its boiling point at normal atmospheric pressure. Reid (1976) defined BLEVEs as the sudden loss of containment of a liquid that is at a superheated temperature for atmospheric conditions.

More recently, less restrictive definitions have been proposed and are being accepted by diverse authors; for example, (CCPS, 1994) an explosion resulting from the failure of a vessel containing a liquid at a temperature significantly above its boiling point at normal atmospheric pressure. To classify an accident as a BLEVE or not will depend on the definition accepted.

The most common type of BLEVE is caused by fire. The steps are as follows:-

a. A liquefied nature gas (LNG) leaks and it lit by fire.
b. The LNG tank is exposed to high temperature fire resulting tank weakening.
c. A crack is caused by the internal pressure; the internal pressure drops abruptly; and
d. The tank ruptures with sudden depressurization and the violent of superheated LNG

If the liquid is flammable and a fire is the cause of the BLEVE, it may ignite as the tank ruptures.

Often, the boiling and burning liquid behaves as a rocket fuel, propelling vessel parts for great distance. If the BLEVE is not caused by a fire, a vapor cloud might form, resulting in a VCE. When a BLEVE occurs in a vessel, only a fraction of the liquid vaporizes; the amount depends on the physical and thermodynamic condition of the vessel contents.

2.6 Available Simulation Tools

Currently, in the engineering world there are a lot of risk assessment tool that able to estimate the effects of BLEVE. One of the models is BLEVE incident simulator (BIS) software. It was developed by of Professor A. M. Birk, 1997. The second model is Atmospheric Dispersion Of Reactive Agent (ADORA). This safety model was developed by COTR Maj. Becky Wagner, 1998. It is the premier Environmental and Safety offsite Consequence Analysis tool available for use by organizations involved with environmental impact assessments for intentional or accidental discharge of hazardous chemicals that react with air, fire or each other. The third model is Software for the Assessment of Flammable, Explosive, and Toxic Impact (SAFETI). This model is a 32-bit software package used for risk assessment and developed by DNV Software Risk Management Solution. SAFETI combines the consequences and frequencies of the hazards to determine the risk.

SAFETI uses built in (DIPPR) chemical and parameter data, along with scenario, meteorological, population, and ignition data supplied by the user to predict the risk form:

a. Designed atmospheric release
b. Accidental atmospheric release of hazardous materials

These models are too general in term of estimating the BLEVE effects in the process plant. In this tool/simulator, the estimation of BLEVE effect is just a minor part.

Although there are many of the safety models commercialized, some of it is not user friendly. In other words, this kind of model is too complicated with their interface and only for advanced users. Some of it also did not cover all of the BLEVE effect such as thermal radiation level, estimation of overpressure, and missile projectile.

2.7 Concluding Remarks

Explosion is depends on a lot of parameters, which it can be either detonation or deflagration. The effects of BLEVE are hazardous and ignorance of BLEVE can caused great loss of human life as well as the properties of plant.

Current hazard analyzing tools are not equipped with combination of BLEVE effects estimation and the function of extracting data from process simulation tools like HYSYS. These tools also is too complicated and not user friendly.

A lot of BLEVE affects estimation methods available nowadays. Nevertheless, all of the tools are developed based on different scenarios of BLEVE. Besides, those methods are based on different assumptions. The differences of methods are interesting for analyzing aspect.

CHAPTER 3

3.0 THEORY

3.1 Case Study

Figure 3.1 illustrated the case study of this project, which is cryogenic process of LNG processing from establish plant. This case study is taken from previous FYP project to show a continuation in the research. The previous research is done by Lau Wai Chong.

Stabilizer C-2502 was utilized as case study in this project. The feed to Stabilizer- 2502, consist of the bottom form the Demethanizer and any propane, which is being re-processed from the liquefaction unit.

From HYSYS simulation, the vapor fraction feed Stabilizer, C-2502 is 0.3223. This showed that Stabilizer, C-2502 is working under highly liquid and less vapor mixture. The release of flammable liquid will create explosion, if the ambient temperature is above the BLEVE limit. Thus, any external exposure of fire at this vessel will, increase the temperature above the BLEVE limit temperature of the compound. Hence, this vessel ill be the best model to be used in this project for calculating the explosion risk such as blast effect, thermal radiation and so on.

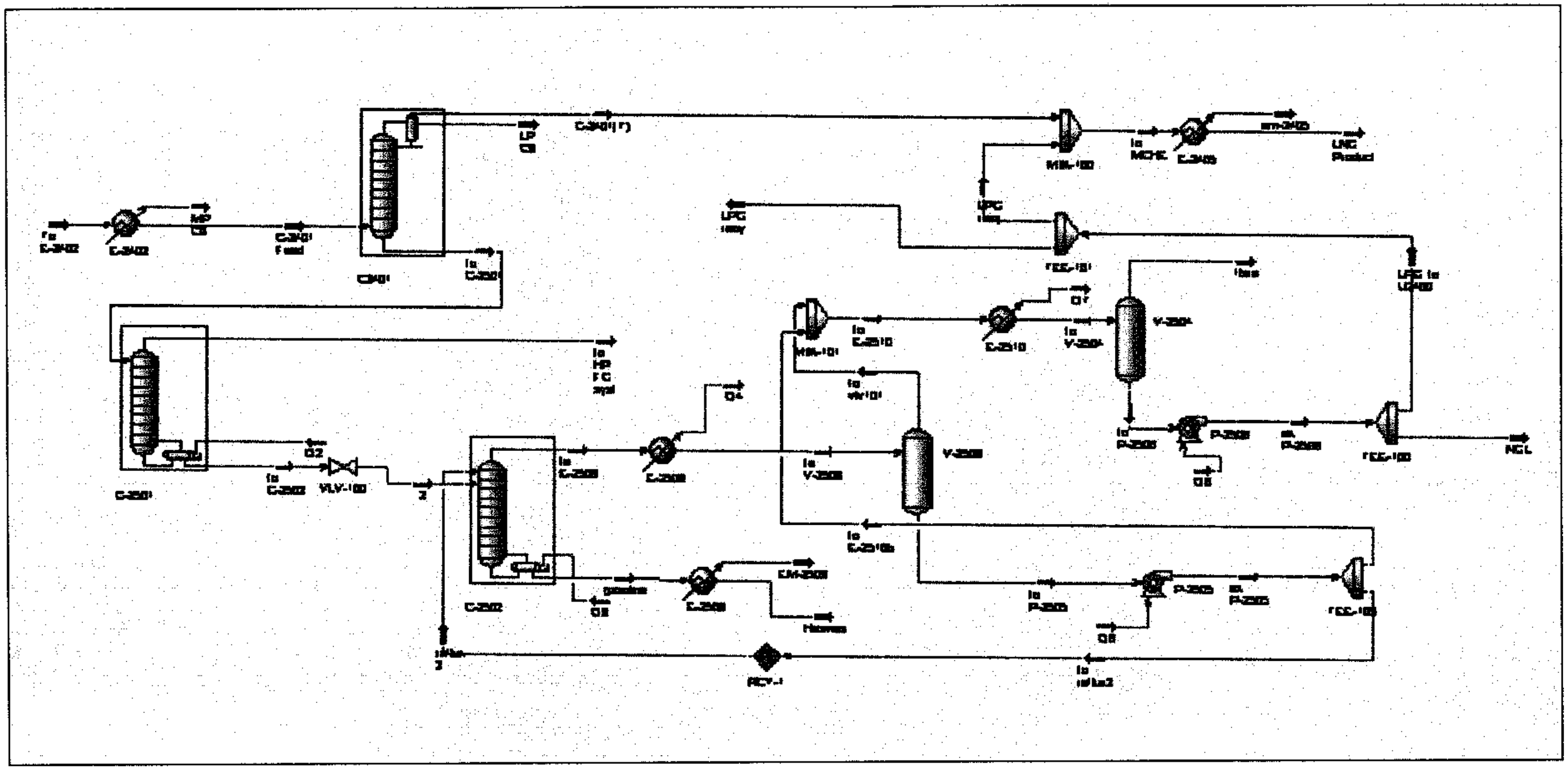


Figure 3.1: HYSYS simulation (Steady –State) of Case Study

3.2 BLEVE Effects Estimation Method

3.2.1 BLEVE Limitation

There is a limitation for BLEVE to take place. According to Reid (1980), BLEVE limitation can be estimated by using the superheat temperature limit, (T_{sl}). The superheat temperature limit is the limit to which compound may be heated before spontaneous nucleation occurs, giving a vapor explosion. If the temperature at current condition of the vessel is greater than the superheat temperature limit of the material, the BLEVE will happen. The correlation between the superheat temperature limit with critical temperature is as below, Reid (1980):

$$T_{sl} = 0.895\ T_c \qquad (1)$$

The critical temperature value for each material that is used can be found in the Perry's Chemical Engineering Handbook thermodynamic properties tables.

3.2.2 BLEVE Blast Effect

The blast wave associated with a BLEVE event is estimated by calculating the total work done by superheated liquid as it expands from its initial condition at the time of vessel failure to atmospheric condition. For storage vessels with properly sized relief valves, it is assumed that the failure pressure of the vessel is 1.21 times the relief valve set point (CCPS, AIChE, 1994).

This approach is recommended by the CCPS (1994). Assuming as isentropic expansion, the total work (W) done by the superheated liquid during the expansion process is given by the following:

$$W = -\Delta U \qquad (2)$$

where ΔU is a change in internal energy of the expanding fluid.

The specific internal energy (u) at a specific state may be obtained directly from thermodynamic tables, or it may be calculated if the specific enthalpy (h), pressure (p) and specific volume (v) are known:

$$u = h - pv \qquad (3)$$

The change in internal energy (ΔU) is then estimated from the following:

$$\Delta U = m_{f,2}u_{f,2} + m_{g,2}u_{g,2} - m_{f,1}u_{f,1} - m_{g,1}\,u_{g,1} \qquad (4)$$

where $m_{f,i}$ and $m_{g,I}$ are the liquid and vapor masses, respectively , at state i, and $u_{f,i}$ and $u_{g,I}$ are the liquid and vapor –specific internal energies, respectively, at state i. The mass of liquid and vapor at final state is estimated form the following:

$$m_{f,2} = (1-x_f)\,m_{f,1} + (1-x_g)\,m_{g,1} \qquad (5)$$

$$m_{g,2} = (x_f)\,m_{f,1} + (x_g)\,m_{g,1} \qquad (6)$$

$$x_f = (s_{f,1} - s_{f,2})/\,(s_{g,2} - s_{f,2}) \qquad (7)$$

$$x_g = (s_{g,1} - s_{f,2})/\,(s_{g,2} - s_{f,2}) \qquad (8)$$

where x_f is a fraction of the initial liquid mass that flashed to vapor, x_g is the fraction of initial vapor mass that does not condense during the explosion, and $s_{f,i}$ and $s_{g,I}$ are the liquid and vapor specific entropies, respectively at state i. if the entropy data are not available, x_f and x_g can be estimated assuming an isenthalpic expansion, where the entropies term in equation (7) and (8) is change to enthalpies terms.

The total work done is converted to the mass of TNT. The equivalent energy of TNT is 1120 cal/gm. The overpressure can be estimated using an equivalent mass of TNT (m_{TNT}) and using the distance (r), from the ground zero point of the explosion. The empirically derived scaling law is, (Joseph F. Louvar, 1990):

$$Ze = r / (mTNT)^{1/3} \qquad (9)$$

Figure 3.1 provides the correlation in SI units: the overpressure is in kPa and the scaling parameter, Ze, is in m/kg $^{1/3}$. Damage estimates based on overpressure are given in Table 3.1.As illustrated; significant damage is expected for even small overpressure.

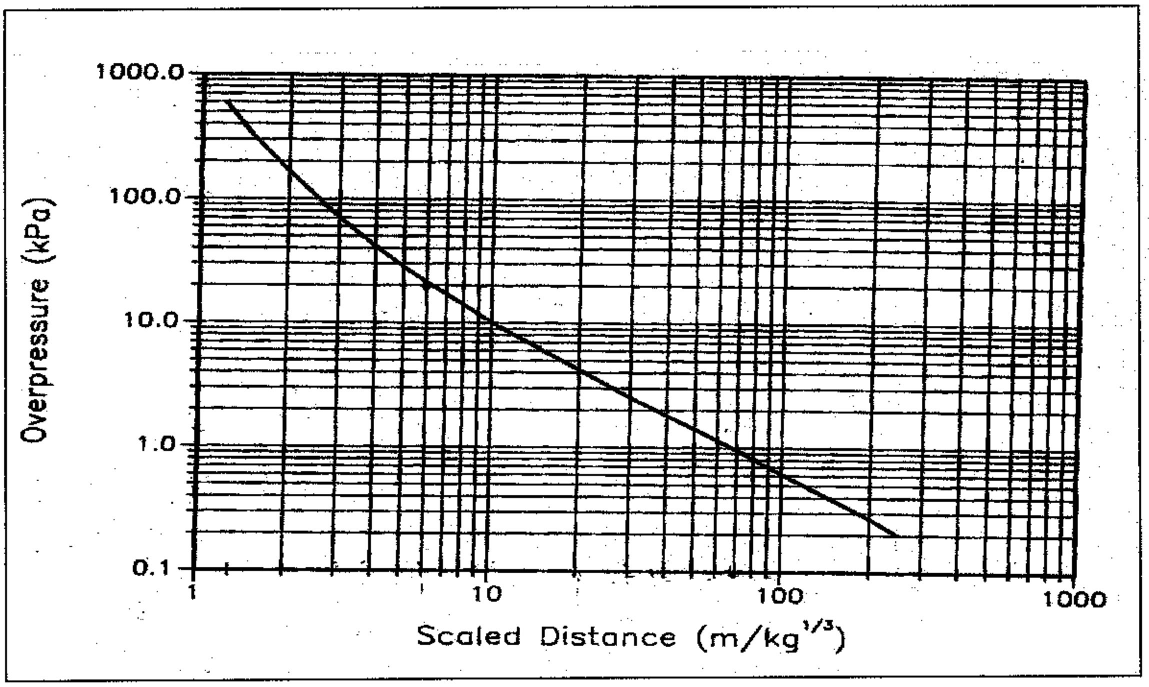


Figure 3.2 Correlation between overpressure and scaled distance SI units (Joseph F. Louvar, 1990).

Overpressure (PSI)	Damage
0.03	Large glass windows which are already under strain broken
0.04	Loud noise. Sonic boom glass failure
0.15	Typical pressure for glass failure
0.3	95% probability if no serious damage
0.5 to 1.0	Large and small windows usually shattered
0.7	Minor damage on house structures
1.0	Partial demolition of houses, made uninhabitable
1.3	Steel frame of clad building slightly distorted
2.0 to 3.0	Non-reinforced concrete or cinder walls shattered
2.3	Lower limit of serious structural damage
3.0	Steel frame building distorted and pulled from foundation
3.0 to 4.0	Rupture of oil storage tank
5.0	Wooden utility poles snapped
5.0 to 7.0	Nearly complete destruction of houses
7.0	Loaded train wagons overturned
9.0	Loaded train boxcars completely demolished
10.0	Probable total destruction of buildings
300.0	Limit of crater lip

Table 3.1: Damage produced by overpressure (Joseph F. Louvar, 1990).

3.2.3 BLEVE Thermal Radiation Effect

The thermal radiation generated from a BLEVE fireball is estimated using a solid flame model that assumes that the fireball is a spherical ball that rises into the air as the flammable material is burned.

The time dependent diameter and height of the fireball and the duration of the fireball are estimated using empirical relationships. The duration of combustion, (t_d) for the BLEVE fireball may be estimated from the following (Martinsen and Marx, 1999):

$$t_d = 0.9\, M_{fb}^{1/4} \qquad (10)$$

where t_d is in second and M_{fb} is the mass of released flammable material in the fireball in kg.

The fireball diameter is time dependent. Based on experimental observation, the fireball tends to reach its maximum diameter during the first third of the fireball duration. At this point, the fireball tends to rise into the air and the diameter remains constant until the fireball dissipates. Martinsen and Marx (1999), present the following equation for estimating the fireball diameter during the growth phase:

$$D\,(t) = 8.664\ M_{fb}^{\ 1/4}\, t^{\ 1/3} \quad \text{for } 0 \leq t \leq 1/3\ t_d \qquad (11)$$

Where D (t) is in meter, M_{fb} is in kg, and t is in second.

At the end of the growth period, the fireball is assumed to achieve its maximum diameter (D_{max}) as given by following equation (Roberts, 1982):

$$D_{max} = 5.8\ M_{fb}^{\ 1/3} \quad \text{for } 1/3\ t_d \leq t \leq t_d \qquad (12)$$

where D_{max} is in meter.

The initial ground flash radius (R_{flash}) associated with a BLEVE fireball is approximated using the following relationship (CCPS, 1999):

$$R_{flash} = 0.65\ D_{max} \qquad (13)$$

where R_{flash} is in meter.

The radius represents the distance that may be engulfed in flames during the initial development of the BLEVE fireball.

The height of the center of the fireball is also time dependent. Based on experiment observations (Martinsen and Marx, 1999), the center of the fireball rises at a constant rate from its lift-off position to three times the lift-off position during the last two – thirds of the fireball duration. This leads to the following equations for the height of the center of the fireball (H_{fb}):

$$H_{fb} = D\,(t)/2 \quad \text{for } 0 \leq t \leq 1/3 t_d \qquad (14)$$

The thermal radiation emitted from the surface of the fireball is also time dependent. The fireball surface emitted flux is assumed to be constant during the growth period; and then is assumed to linearly decrease from its maximum value to zero during the last two-thirds of the fireball duration. The maximum surface emitted thermal flux (E_{max}) during the growth phase is given by the following (Martinsen and Marx, 1999):

$$E_{max} = 0.0133\ f\ H_c\ M_{fb}{}^{1/12} \text{ for } 0 \le t \le 1/3t_d \qquad (15)$$

Where E_{max} is in kW/m^2, f is the radiant heat fraction, H_c is the net heat of combustion of the flammable material in kJ/kg and M_{fb} is in kg.

The radiant heat fraction (f) is given by the following (Roberts, 1982):

$$f = 0.27\ P_B{}^{0.32} \qquad (16)$$

where f is dimensionless and P_B is the burst pressure of the vessel in MPa.

Fire research suggests that the maximum surface emitted flux, E_{max} will not exceed some upper limit ragging from 300 to 450 kW/m^2. A value of 450 kW/m^2 is suggested as a limiting value (Martinsen and Marx, 1999). Therefore, the lesser of the surface emitted flux given by the equation (1) should be used. During the last two –thirds of the fireball duration, the surface emitted flux (Es) is given by the following:

$$Es\ (t) = E_{max}\ [1.5\ (1\text{-}t/t_d)] \qquad \text{for } 1/3t_d \le t \le t_d \qquad (17)$$

The thermal flux incident upon a target object is a function of geometric view factor between the fireball and the target. The most conservative approach assumes that the target area is normal to the surface of the fireball as the fireball rises into the air.

For a target at ground level, the maximum geometric factor (F) for a spherical emitter is given by the following equation (CCPS, AIChE, 1994):

$$F(x,t) = [X^*\ ((Dmax/2)^\wedge 2\ )]/[\ (x^\wedge 2 + H^\wedge 2)^\wedge 1.5\ ] \qquad (18)$$

Where F is dimensionless and D, H_{FB} and x are in meter.

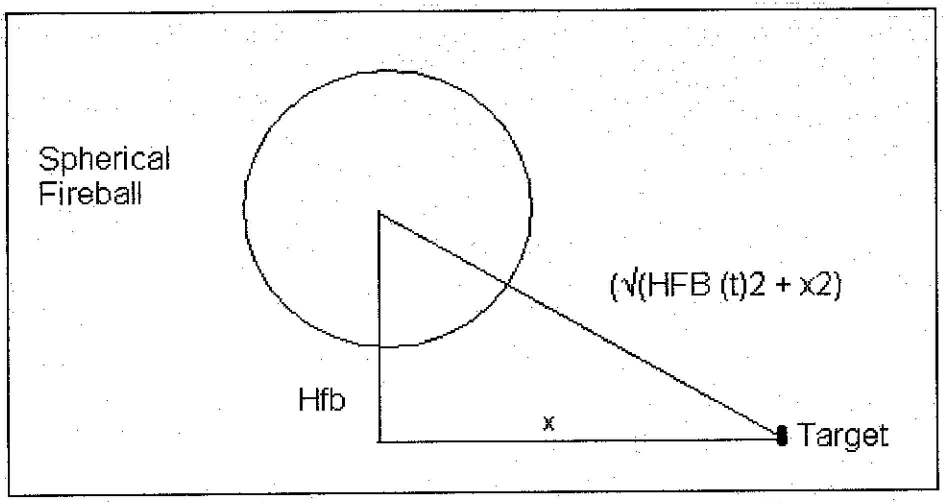


Figure 3.3: Assumed Orientation of a Ground level Target to the Fireball Surface (CCPS, AIChE, 2000)

The atmospheric trasnmissivity (τ) between the fireball and the target is estimated from the following equation (CCPS, AIChE, 1999):

$$\tau\,(x,t) = 2.02\ [\ R\ Pv\ (\sqrt{(H_{FB}\,(t)^2 + x^2)} - D(t)/2)]^{-0.09} \qquad (19)$$

where τ is dimensionless, R is the fractional relative humidity (e.g., for 70% relative humidity, R is 0.7), and Pv is the saturated vapor pressure of water at the ambient temperature in Pa. the thermal flux (I_{th}) at a target is given by the following equation (CCPS,1999):

$$I_{th}\,(x,t) = \tau\,(x,t)^*\ F(x,t)^*\ Es\,(t) \qquad (20)$$

Where I_{th} is in kW/m^2.

Personal injuries resulting from the exposure to a BLEVE fireball are dependent upon the thermal dose (I_{dose}) or integral of the thermal flux over the duration of the fireball.

$$I_{dose}\,(x) = {}^{td}{}_{0}\!\int I_{th}\,(x,t)\ dt \qquad (21)$$

Where I_{dose} is in kJ/m^2.

Table 3.2 (Prugh 1994) summarizes the type of injury that may result from various thermal dose level.

Injury Description	Thermal Dose (kJ/m^2)
Third-degree burns (99% fatal)	1200
Third-degree burns (50% fatal)	500
Third-degree burns (1% fatal)	250
Second-degree burns (Blisters)	150
First-degree burns (sunburns)	100
Threshold of pain	40

Table 3.2: Thermal Dose Injury Criteria (Prugh, 1994)

3.2.4 BLEVE Missile Projectile Effect

BLEVE events often generate large vessel fragments that may be propelled long distances. In fact, in many cases, the longest reaching hazard associated with BLEVE events is projectiles or rocket-type fragments. The fragments associated with BLEVE generally not evenly distributed. The vessel's axial direction usually receives more fragments than the side directions, but it is not unusual for a vessel to pivot or spin during the failure. Therefore, fragments can be launched in any direction. The trajectory of the propelled fragment can also be bouncing off terrain or structure.

According to Birk (1995), as a crude approximation, projectile ranges can be related to the fireball radius. The following is suggested as a guide:

a) 80 to 90 % of rocketing fragments fall within 4 times the fireball radius
b) Severe rocketing fragments may travel up to 15 times the fireball radius
c) In very severe, rare cases, rocketing fragments may travel up to 30 times the fireball radius.

3.3 Concluding Remarks

In this research, there are four major parts has being studied. The BLEVE limitation is where the limit of BLEVE event is set. According to the definition, BLEVE is different from other explosion such as Vapor Cloud Explosion and so on. The event only can call as a BLEVE is when a vessel or storage tank exposed to external fire and when the temperature at current condition of the vessel is greater than the superheat temperature limit of the material.

Blast effect is one of the hazardous effect can caused by BLEVE. In this effect the important parameter that needs to take into consideration is the overpressure for the explosion. The damage produce by overpressure is summarized in Table 3.1. The second effect from BLEVE event is thermal radiation. In the BLEVE event, the fireball will be occurred. The thermal radiation will effect in certain radius from the source of the fireball. Figure 3.2 showed the assumed orientation of ground level target to the fireball (CCPS, AIChE, 2000).

The third effect is the missile projectile. In this effect, a lot of assumption has being made. The trajectory of the missile is calculated in two dimensions accounting for resistance of air proportional to the square of its velocity. This applies to the so-called ballistic range which lies between very low velocities, where resistance is proportional to velocity, and supersonic velocities where resistance is a complex function. Fragments from vessel bursts are usually encountered in this range.

CHAPTER 4

4.0 METHODOLOGY/ PROJECT WORK

4.1 Procedure identification

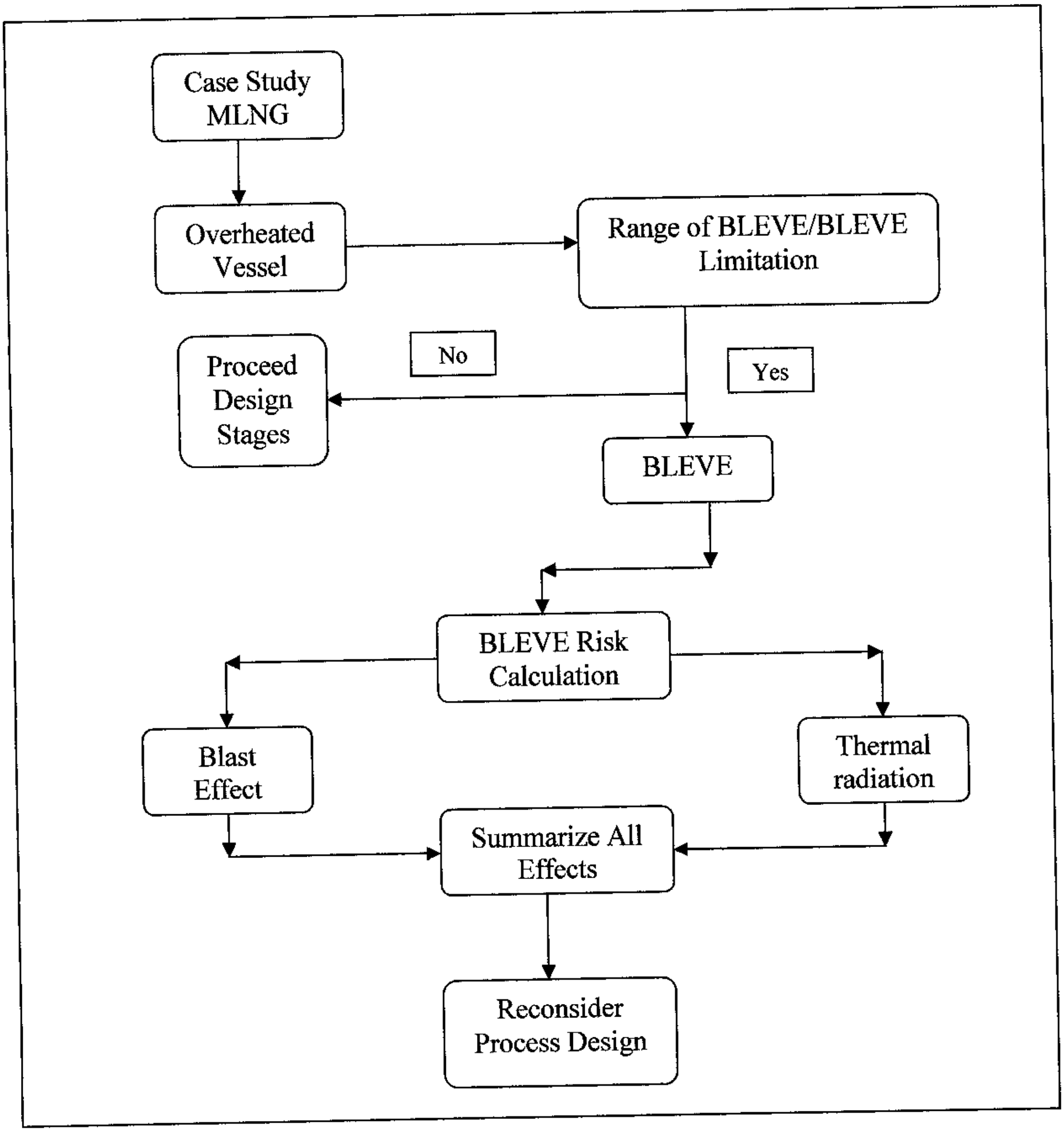


Figure 4.1: Methodology of project

4.2 Case Study

In this project, a process in established LNG plant was utilized as one of the case study. This case study was simulated by using process simulator, HYSYS. In this project, HYSYS simulator acted as "live" thermodynamic database. Based on the case study (steady state) simulation, the needed composition and properties of the process can be obtained and then extracted to Microsoft Excel for effect estimation.

4.3 Overheated Vessel

The objective of this project is to study the BLEVE effects. Before BLEVE took place, the vessel need to be overheated. In other words, the vessel containing a liquid at a temperature significantly above its boiling point at normal atmospheric pressure.

4.4 Range of BLEVE limit

There is a limitation for BLEVE to take place. According to Reid (1980), BLEVE limitation can be estimated by using the superheat temperature limit, ($\mathbf{T_{sl}}$). The superheat temperature limit is the limit to which compound may be heated before spontaneous nucleation occurs, giving a vapor explosion. If the temperature at current condition of the vessel is greater than the superheat temperature limit of the material, the BLEVE will happen.

4.5 Boiling Liquid Expanding Vapor Explosions (BLEVE)

The BLEVE will occur when the temperature at current condition of the vessel exceed the superheat temperature limit. If the temperature at current condition did not exceed the BLEVE limitation, the process design stage can be continued.

4.6 Mathematical Calculation in Microsoft Excel

Mathematical calculations were carried out under Microsoft Excel platform in estimating the BLEVE effects such as blast, thermal radiation and missile projectile.

In TNT equivalent method, explosion energy of the vessel or storage tank was determined based on the composition of the gas/liquid mixture and their heat of combustion. Then, scaled distance, Z at specific radius was calculated. Lastly BLEVE blast effect was estimated based on establish effects and overpressure relationship.

Four parameter used to determine a fireball's thermal radiation hazard are the mass of the fuel involved and the fireball's diameter, duration and thermal emissive power (AIChE,1994). The radiation hazards are then calculated using empirical relation.

4.7 Summarizing All the Effects

The result of the effects were summarized and justified. This is important to the user so that, the result of the effects can be evaluated and understood.

4.8 Reconsider Process Design

After all the effects were summarized and justified, the user need to reconsider the process design in order to make sure the BLEVE will not take place. This can be done by changing the process parameter such the temperature, pressure and so on.

CHAPTER 5

5.0 RESULT AND DISCUSSION

5.1 Case Study

The Figure 3.1 was utilized as case study in this project. Nevertheless, HYSYS simulation case that was illustrated as figure 3.1 is complicated. Hence, a simplified model of the Stabilizer C-2502 was simulated as Figure 5.1 below to ease vessel properties extracting process.

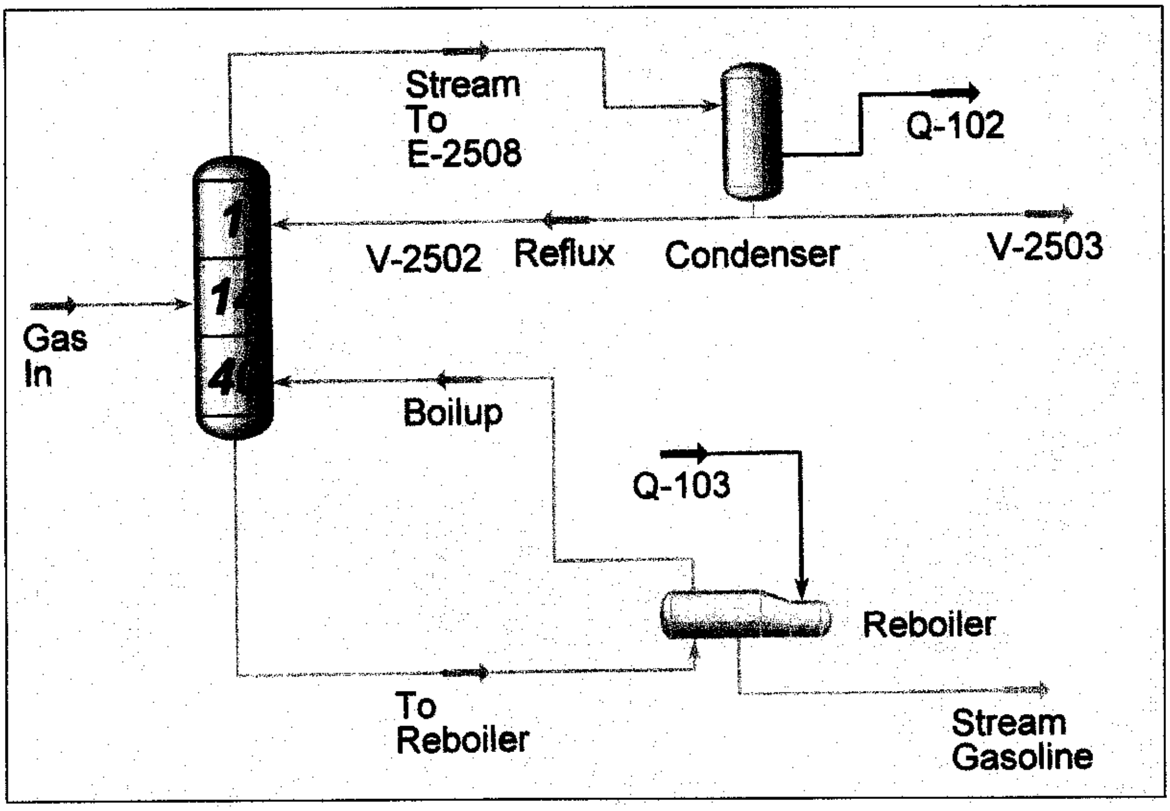


Figure 5.1: Simulation of Stabilizer C-2502

In this case study, some assumption need to be made before we can proceed to the calculation of BLEVE effects estimation. In the Stabilizer C-2502, it contain high amount of propane compared to other component such as methane, ethane, butane and pentane. In this case study we consider only propane due to its high volume/amount in the Stabilizer C-2502.

A 10, 000 gallon vessel is assumed to fail at an internal pressure of 1.21 time of the set point of safety relief valve, 121 psi. The saturation temperature of propane at 121 psi is 333.55 K. This defines the initial for calculation of the change in internal energy. The final conditions of the propane are atmospheric pressure (14.7 psi) and the normal boiling point of propane is 266 K. Table 5.1 summarizes the thermodynamic data propane at initial and final conditions (Perry Chemical Engineers' Handbook 1998).

Condition	**Temp (K)**	**Pressure (psi)**	**hf (Btu/lb)**	**hg (Btu/lb)**	**vf (ft^3/lb)**	**vg (ft^3/lb)**	**sf (Btu/lb-R)**	**sg (Btu/lb-R)**
1 (initial)	333.55	121.00	300.00	409.20	0.038	0.311	1.153	1.337
2 (final)	266.00	14.700	181.20	365.10	0.028	6.696	0.925	1.367

Table 5.1 Thermodynamic Data for Propane Case Study (Perry Chemical Engineers' Handbook 1998)

5.2 BLEVE Limitation

5.2.1 BLEVE Limitation Calculation

	Compound thermodynamic Properties	
Name of compound	Propane	
Critical temperature	369.80	K
Critical Pressure	42.50	Bar
Temperature (initial)	333.55	K
Pressure (initial)	8.23	Bar
Temperature (final)	266.00	K
Pressure (final)	1.00	Bar

	BLEVE Limitation	
Superheat limit temp.	330.971	K
BLEVE	Yes	

Table 5.2: BLEVE Limitation Data and Calculation

All initial data from the case study is summarized and calculated in the Table 5.2. The critical temperature for propane is 369.8 K. By using equation 1, the superheat limit temperature for propane is 330.971 K.

5.2.2 BLEVE Limitation Discussion

In this case study the temperature of the propane is about 333.55 K, which is exceeding the superheat limit temperature. When this condition happened, the BLEVE will occur. If the BLEVE is possible to occur, the users need to proceed to the effects estimation which is blast and thermal radiation effect.

5.3 BLEVE Blast Effect

5.3.1 BLEVE Blast Effect Calculation

The blast wave associated with a BLEVE event is estimated by calculating the total work done by superheated liquid as it expands from its initial condition at the time of vessel failure to atmospheric condition. The change in internal energy and total work done by the explosion is calculated by using equation 4.

The total work done is converted to the mass of TNT. The overpressure can be estimated using an equivalent mass of TNT (m_{TNT}) and using the distance (r), from the ground zero point of the explosion. It can be determine by using equation 9.

	Change in internal energy	
Delta U	-9.21E x 10^5	Btu
Work	9.21 x 10^5	Btu
	9.71 x 10^8	joule
	2.32 x 10^5	cal

Table 5.3: Change in Internal Energy and Work Done by the Explosion

TNT Equivalent		
TNT equivalent	2.07 x 10^2	g TNT
Mass TNT, (Mtnt)	2.07 x 10^{-1}	kg TNT
Radius, r	10	m
Scaling parameters,(Ze)	1.68 x 10^1	m/kg$^{1/3}$

Table 5.4: Scaling and Explosion Parameter

The value of the overpressure in this case study can be determined from the graph in Figure 2.1. The effect for the overpressure also can be determined from Table 2.2. In this case study, explosion parameter were determined through the specified radius which are 10m, 20m, 30m, 40m, 50m.

5.3.2 BLEVE Blast Effect Discussion

The overpressure and the effect of explosion with respect to the explosion parameter are summarized in the Table 5.5. In this case study, the overpressure at radius 10 meter is 0.87 psi. At this overpressure rate, it is a partial demolition of houses, made uninhabitable.

From the data from Table 5.5, a graph of the relationship of overpressure versus radius is plotted. From the graph the trends can be observed more clearly.

Radius (meter)	Overpressure (psi)	Damage
10	0.87	Partial demolition of houses, made uninhabitable
20	0.34	Large and small windows usually shattered
30	0.22	95% probability if no serious damage
40	0.15	Typical pressure for glass failure
50	0.1	Typical pressure for glass failure

Table 5.5: The Overpressure and Damage With Respect to the Explosion Parameter.

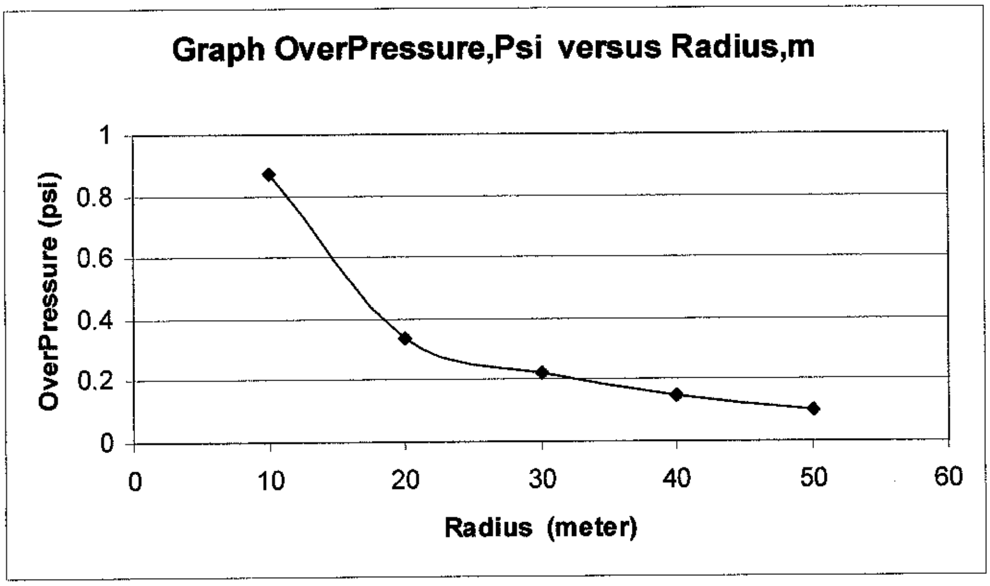


Figure 5.2: Graph Overpressure, Psi versus Radius, m for BLEVE Explosion

Figure 5.2 showed the relationship of overpressure versus radius. The radius is measured from the ground zero point of the explosion. The trends showed that overpressure dramatically decrease with the increasing of radius. Then until certain stage, the rate of decreasing becomes slower. This type of relationship was proven to be correct referred to Figure 3.2. (Joseph F. Louvar, 1990)

In this Final Year Project, the result from this model is compared to the result from SAFETI Software. The SAFETI Software has being established for many years and well known in the process industries. This is to validate the result the obtained from BLEVE model.

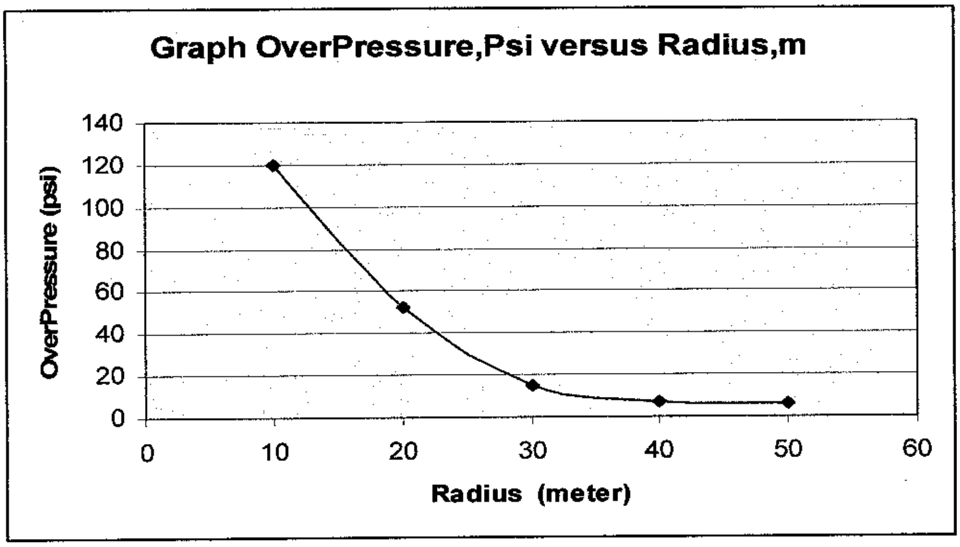


Figure 5.3: Graph BLEVE Overpressure versus Distance Downwind. (SAFETI Software)

Figure 5.3 showed the relationship of overpressure versus distance from the SAFETI Software. The trends showed that overpressure dramatically decrease with the increasing of distance. This trend is similar with the trends of the Figure 5.2 (result from BLEVE model). Although the value is not the same from both model, but the graph from the BLEVE model still achieve the right trend.

There are some factors that SAFETI Software takes into its calculation of blast effect which the BLEVE model did not consider. The factors are weather condition, wind condition, mass correction factor and so on. The line show that the effect is being considered in the windy condition was the velocity of the wind 1.5 m/s. All of these factors will contribute to the different in value of radiation level compared to the result from BLEVE model/tool.

In TNT Equivalent Method (J.M. Santamaria Ramiro, 1998), it was justified that the explosion efficiency depends on the method for determining the contributing mass of fuel. Models based on total quantity released have lower efficiencies. Meanwhile models based on the dispersed cloud mass have higher efficiencies. Nevertheless, in this method, it only utilized a constant efficiencies factors which between 1% and 10% for most explosion. Hence, the application of explosion efficiency represents one of major problems with the TNT Equivalent Method.

5.4 BLEVE Thermal Radiation Effect

5.4.1 BLEVE Thermal Radiation Calculation

Four main parameters used to determine a fireball's thermal radiation hazard are the mass of fuel involved, the fireball's diameter, duration and thermal emissive power (AIChE, 1994). In this thermal radiation effect, thermal dose is being considered. Below is table of the important values in thermal radiation calculation.

Data	Value	Units
Mass release flammable material. (Mfb)	21276.450	kg
Duration of combustion,(td)	10.870	seconds
Maximum Diameter, (Dmax)	155.466	meter
Height of the center fireball, (Hfb)	80.014	meter
Distance, (x) : > (Dmax/2)	80	meter
Thermal Flux,(Ith)	66.347	kW/m^2
Thermal Dose,(Idose)	721.171	kJ/m^2

Table 5.6: Result for BLEVE Thermal Radiation Effect Calculation.

The time duration of the combustion is calculated by using equation 10. In this case study the time take is only 11 seconds. The effect for the thermal dose can be determined from Table 3.2. In this case study, explosion parameter were determined through the specified distance which are 80m, 90m, 100m, 110m, 120m.

5.4.2 BLEVE Thermal Radiation Discussion

The thermal dose and the effect of radiation with respect to the radiation parameter are summarized in the Table 5.7. In this case study, the thermal radiation at radius 80 meter is 721.171 kJ/m^2. At this radiation rate, it causes a third degree burn, in other words 99% fatality.

Distance, L(meter)	Thermal Dose (kJ/m^2)	Injury Description
80	721.171	Third-degree burns (99% fatal)
90	661.7	Third-degree burns (99% fatal)
100	602.25	Third-degree burns (99% fatal)
110	545.702	Third-degree burns (50% fatal)
120	439.476	Third-degree burns (50% fatal)

Table 5.7: The Thermal Dose Radiation and Injury Description with Respect to the Radiation Parameter

From the data from Table 5.7, a graph of the relationship of thermal dose radiation versus distance is plotted. From the graph the trends can be observed more clearly.

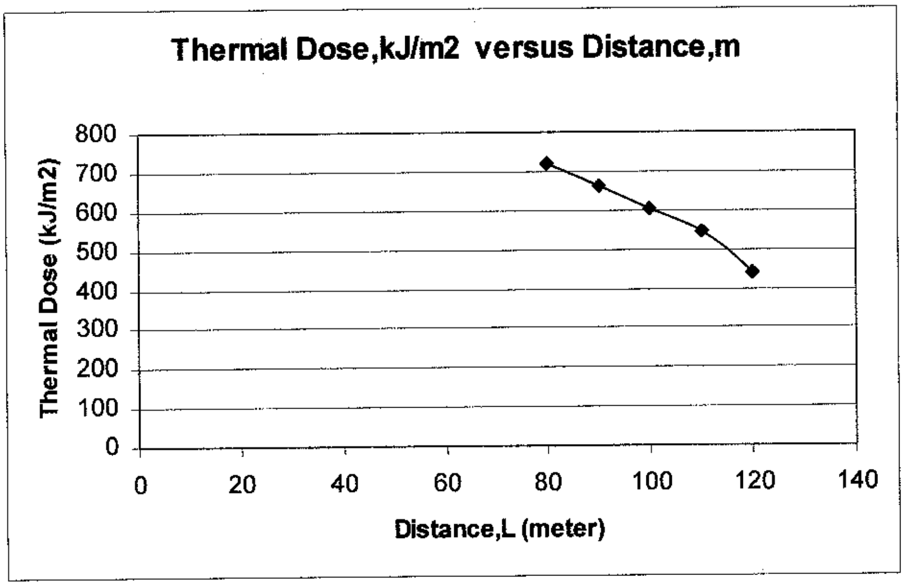


Figure 5.4: Graph Thermal Dose Radiation versus Distance Radiation

Figure 5.4 showed the relationship of thermal dose radiation versus distance of radiation. The distance is measure from the point at the ground directly beneath the center of the fireball to the receptor at the ground level as shown in Figure 3.3. The trends showed that thermal dose radiation decrease with the increasing of distance of radiation. AIChE (1994) suggest using an emissive power of 350 kJ/m2 for large scale release of hydrocarbon fuel, with the power increasing as the scale of release decrease. This type of relationship was proven to be correct referred above statement.

This graph is compared to the graph which obtained from SAFETI Software by using same case study. This is to validate the result which obtained from the BLEVE model.

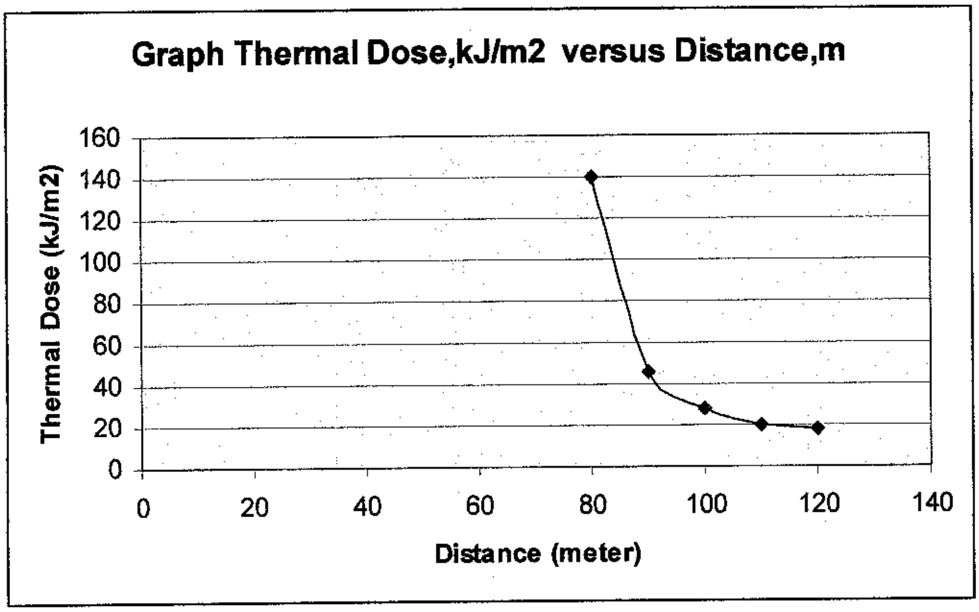


Figure 5.5: Graph Radiation Level versus Distance Downwind. (SAFETI Software)

Figure 5.5 showed the relationship of radiation level versus distance from the SAFETI Software. The trends showed that radiation level decrease with the increasing of distance. This trend is similar with the trends of the Figure 5.4 (result from BLEVE model). Although the value is not the same from both model, but the graph from BLEVE model still achieve the right trend.

In the thermal radiation calculation, SAFETI Software has considered the angle of the explosion, the frequency of accident to happen, the shape of vessel, weather and wind condition and ect. The line show that the effect is being considered in the windy condition was the velocity of the wind 1.5 m/s. All of these factors will contribute to the different in value of radiation level compared to the result from BLEVE model/tool.

The problem with a fireball typical of a BLEVE is that the radiation will depend on the actual distribution of flame temperature, the composition of the gases in vicinity of the fireball (including reactants and products), the geometry of the fireball, absorption of the radiation by the fireball itself and the geometry relationship of the receiver with respect to the fireball. All these parameters are difficult to quantify for a BLEVE.

5.5 Concluding Remarks

The BLEVE limitation is where the limit of BLEVE event is set. According to the definition, BLEVE is different from other explosion such as Vapor Cloud Explosion and so on. The event only can call as a BLEVE is when a vessel or storage tank exposed to external fire and when the temperature at current condition of the vessel is greater than the superheat temperature limit of the material.

BLEVE blast effect is estimated by determine the total of work done by the explosion and converted to the mass of TNT. The scaling law and the correlations of Figure 2.1 to estimate the overpressure and to estimate the damage is on Table 2.2. In blast effect estimation, the trend of the graph overpressure versus radius showed that overpressure dramatically decrease with the increasing of radius. Then until certain stage, the rate of decreasing becomes slower. This type of relationship was proven to be correct referred to Figure 3.2. (Joseph F. Louvar, 1990)

In thermal radiation method, there are 4 important parameters that need to take into consideration. The parameters are the mass of fuel involved, the fireball's diameter, duration and thermal emissive power (AIChE, 1994). The result of the thermal radiation can be observed via Figure 5.4. The trend of the graph of thermal dose radiation versus distance of radiation is proved by the statement in AIChE, 1994.

All of these results are compared to the established safety software, SAFETI. Although the value which obtained from the SAFETI Software is not exactly the same, but the trend of both graph is similar with our BLEVE tools. This is because, SAFETI consider a lot of factor such as angle of explosion, weather, wind condition, the shape of vessel, the frequency of accident to happen in estimating the effect of BLEVE. All of these factors will contribute to the different in value in effect estimation compared to the result from BLEVE model/tool.

CHAPTER 6

6.0 CONCLUSION

As conclusion, the main objectives were accomplished. The desired data from HYSYS is extracted to ME interface to performs the calculation and effect estimation. BLEVE limitation was estimated using the superheat limit temperature. The blast effect was estimated by using the TNT equivalent method and for the thermal radiation effect estimation the thermal dose method was used. All of the effects and limitation was summarized and justified.

This project has great potential in becoming a commercial tool in the future, for considering the loss and prevention aspect during the conceptual design stage. Hence, it is recommended that more efforts and further development should be spent in improving this tool.

CHAPTER 7

7.0 PROBLEMS AND RECOMMENDATIONS

7.1 Problems Encountered

A few problems were encountered during the progress of the project. The thermal radiation effect and BLEVE limitation can not be carried out initially because there are not many references of the thermal radiation effect and BLEVE limitation. The way of approached is little bit different instead using the BLEVE limitation, the lower and upper explosion limit is always being used. Hence, more literature reviews were carried out in finding the latest method to approach the BLEVE limitation and thermal radiation effects.

For the missile projectile effect, the effect can not be carried out in this research due to some limitation such as the literature review and so on. In this research there are only some assumptions to estimate this effect.

The calculation of these risks and consequences measuring method will no be too user friendly for those who just came across it. Thus, a ME interface was created in the simplest way to display he result of the project in a more user friendly interface without showing the complicated background programs.

7.2 Recommendations

Further development of this project is recommended due to the commercial potential that is embedded in it. This is due to the fact that this type of loss prevention tool currently is not available with any of the chemical simulators such as Aspen, PRO2, and HYSYS. Beside that, this tool can be improve more in the effect estimation by considering other factors such as weather, wind condition, the angle of explosion, geometry of the fireball, adsorption of the radiation by the fireball itself, the geometry relationship of the receiver with respect to the fireball and so on. By considering all these factors, the tool accuracy will be higher .The present of this tool provide the essential BLEVE effects estimation at the earlier stage of the plant conceptual design. It also allows process engineers consider the loss and prevention aspect at the earlier stage of plant design. For example, location consideration of pipeline and pressurized equipment after determining the effects of explosion.

In this Final Year Project, only BLEVE was considered in the calculation. Thus, a lot further development can be done based on this project. Firstly it can be integrated with ME and Visual Basic, which is can also include the entire desired database in conducting all the necessary calculation in estimating the effects of explosions. The explosion also not only limited to BLEVE, but also UVCE, confined VCE and so on.

Beside, other new interface can be developed which will acts as medium to return the optimum range or safety range of material composition or any desire property of the stream to HYSYS that will prevent the BLEVE from occurring.

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APPENDIX A

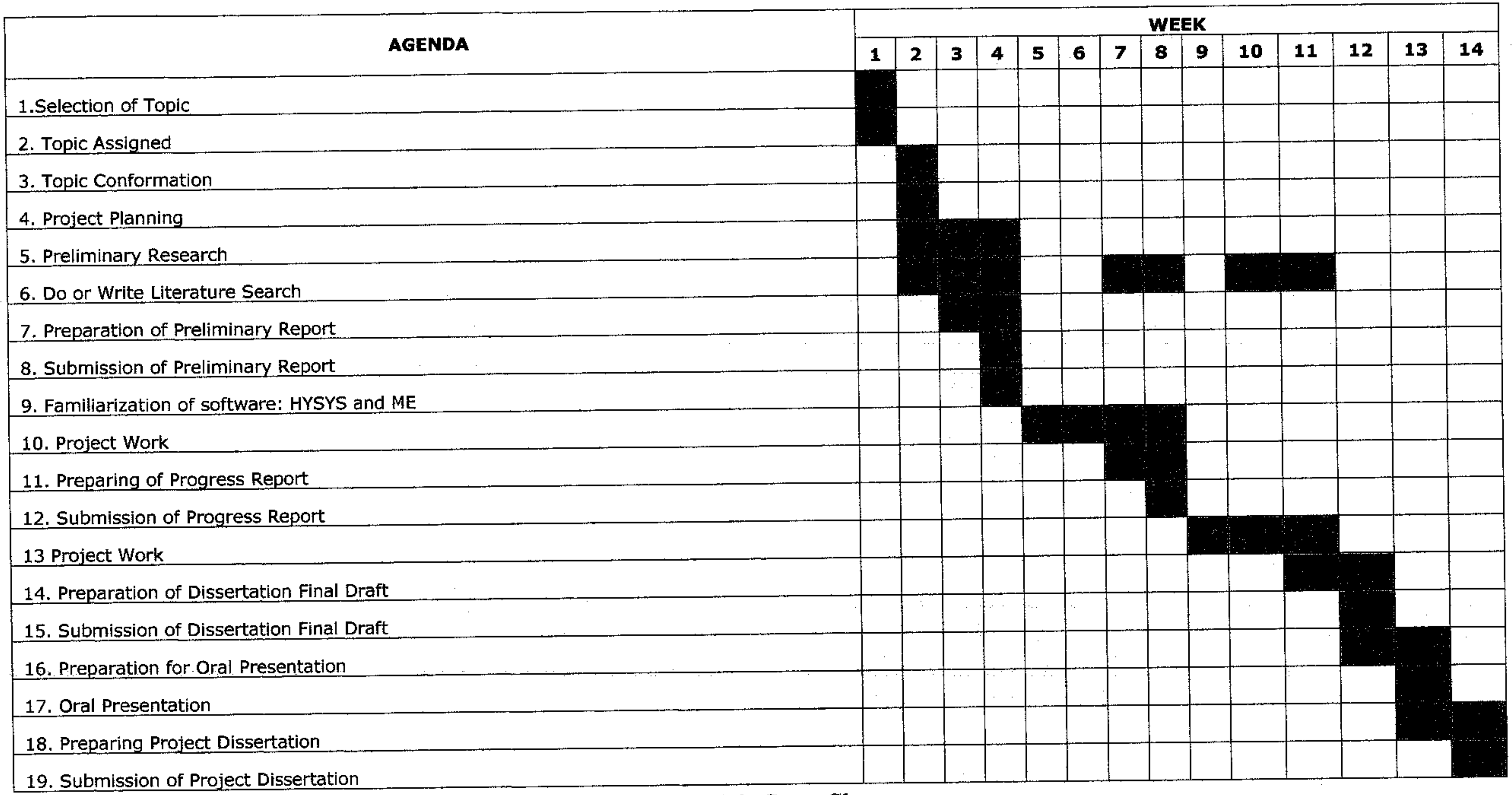


Figure A.1: Gantt Chart

APPENDIX B

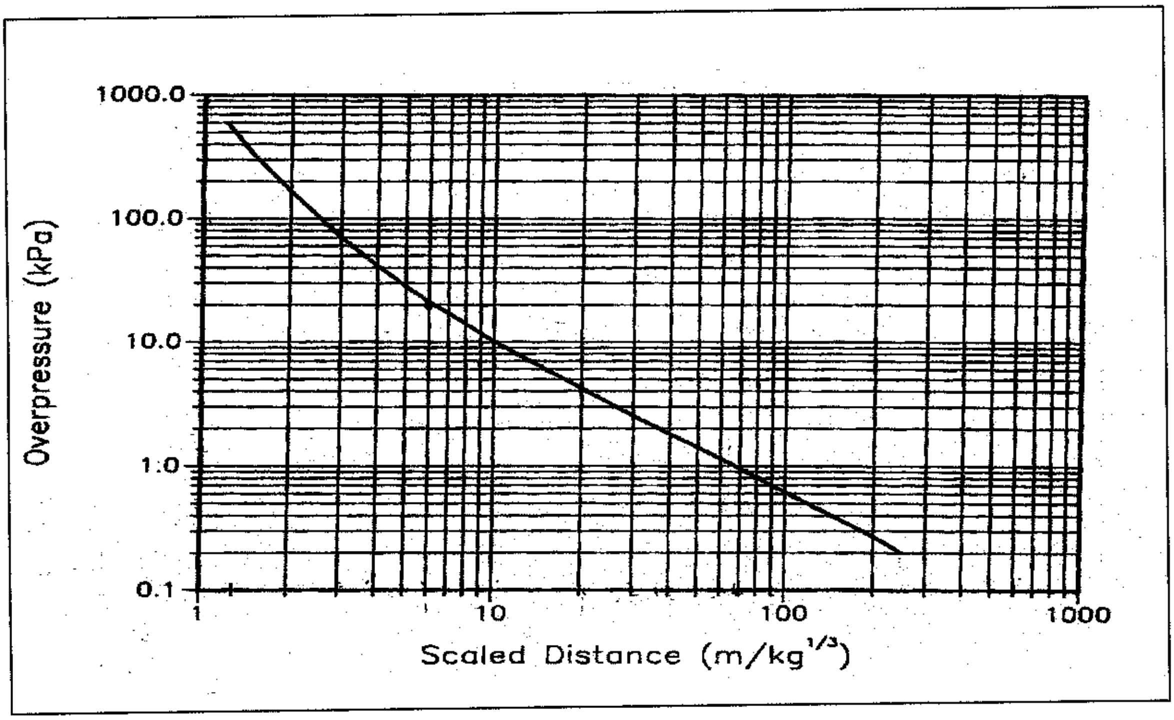


Figure B.1 Correlation between overpressure and scaled distance SI units (Joseph F. Louvar, 1990).

Table B.1: Thermal Dose Injury Criteria (Prugh, 1994)

Injury Description	Thermal Dose (kJ/m2)
Third-degree burns (99% fatal)	1200
Third-degree burns (50% fatal)	500
Third-degree burns (1% fatal)	250
Second-degree burns (Blisters)	150
First-degree burns (sunburns)	100
Threshold of pain	40

Overpressure (PSI)	Damage
0.03	Large glass windows which are already under strain broken
0.04	Loud noise. Sonic boom glass failure
0.15	Typical pressure for glass failure
0.3	95% probability if no serious damage
0.5 to 1.0	Large and small windows usually shattered
0.7	Minor damage on house structures
1.0	Partial demolition of houses, made uninhabitable
1.3	Steel frame of clad building slightly distorted
2.0 to 3.0	Non-reinforced concrete or cinder walls shattered
2.3	Lower limit of serious structural damage
3.0	Steel frame building distorted and pulled from foundation
3.0 to 4.0	Rupture of oil storage tank
5.0	Wooden utility poles snapped
5.0 to 7.0	Nearly complete destruction of houses
7.0	Loaded train wagons overturned
9.0	Loaded train boxcars completely demolished
10.0	Probable total destruction of buildings
300.0	Limit of crater lip

Table B.2: Damage produced by overpressure (Joseph F. Louvar, 1990).

Table B.3: Saturated Vapor Pressure of Water as a Function of Temperature (AiChe, 1998)

Tempreature ©	Vapor Pressure (Pa)
1	660
2	705
3	759
4	813
5	874
6	935
7	1003
8	1070
9	1150
10	1230
11	1310
12	1400

13	**1500**
14	**1600**
15	**1710**
16	**1820**
17	**1940**
18	**2060**
19	**2200**
20	**2340**
21	**2490**
22	**2650**
23	**2810**
24	**2990**
25	**3170**
26	**3360**
27	**3570**
28	**3780**
29	**4010**
30	**4250**
31	**4500**
32	**4760**
33	**5040**
34	**5330**
35	**5630**
36	**5950**
37	**6280**
38	**6630**
39	**7000**
40	**7390**
41	**7790**

STREAMS		17		18	19	20	21	22	23		24	25		26	27	29	30		31	32	35	36	37
PARAMETER	UNITS	VAP	LIQ	VAP	LIQ	VAP	LIQ	VAP	VAP	LIQ	VAP	VAP	LIQ	LIQ	LIQ	LIQ	VAP	LIQ	LIQ	LIQ	VAP	LIQ	LIQ
TEMPERATURE	°C	-11.9	-11.9	-11.8	53.1	108.0	108.0	-12.8	75.3	75.3	52.0	40.0	40.0	40.0	-30.0	124.2	128.5	128.5	127.9	35.0	-25.8	-30.0	40.0
PRESSURE	BARA	24.91	24.91	24.91	25.00	25.00	25.00	23.50	7.79	7.79	7.64	7.14	7.14	7.64	6.74	8.03	8.03	8.03	7.93	7.43	6.74	6.74	10.60
FLOW	KG/S	0.38	5.55	0.68	7.48	2.23	5.25	0.68	1.61	3.64	4.72	2.01	2.71	2.71	2.02	15.44	4.63	10.81	3.24	3.24	0.01	2.01	0.00
ACTUAL DENSITY	KG/M3	23.36	608.3	23.34	532.7	45.33	489.3	21.99	15.50	574.9	16.79	14.85	533.9	534.1	584.9	539.8	21.66	543.4	544.3	647.8	6.25	584.9	533.9
MOLECULAR WEIGHT	KG/KGMOL	18.40	57.26	18.39	57.63	40.48	65.02	18.39	51.72	73.39	51.80	47.99	55.05	55.05	47.99	80.97	76.33	83.14	83.16	83.16	18.40	47.99	55.05
VISCOSITY	CP	0.011	0.185	0.011	0.110	0.013	0.088	0.011	0.010	0.144	0.009	0.009	0.111	0.111	0.173	0.117	0.010	0.120	0.121	0.252	0.010	0.173	0.111
DESIGN FLOW	KG/S	1.29	13.23	2.19	16.35	4.02	12.33	2.19	3.41	8.92	14.24	8.71	5.52	5.27	8.97	49.27	14.78	34.49	4.69	4.69	0.024	8.97	1.50
																			CASE 3	CASE 3	CASE 3		

NOTE 3

Table C.1: Plant Parameters (Established LNG Plant)

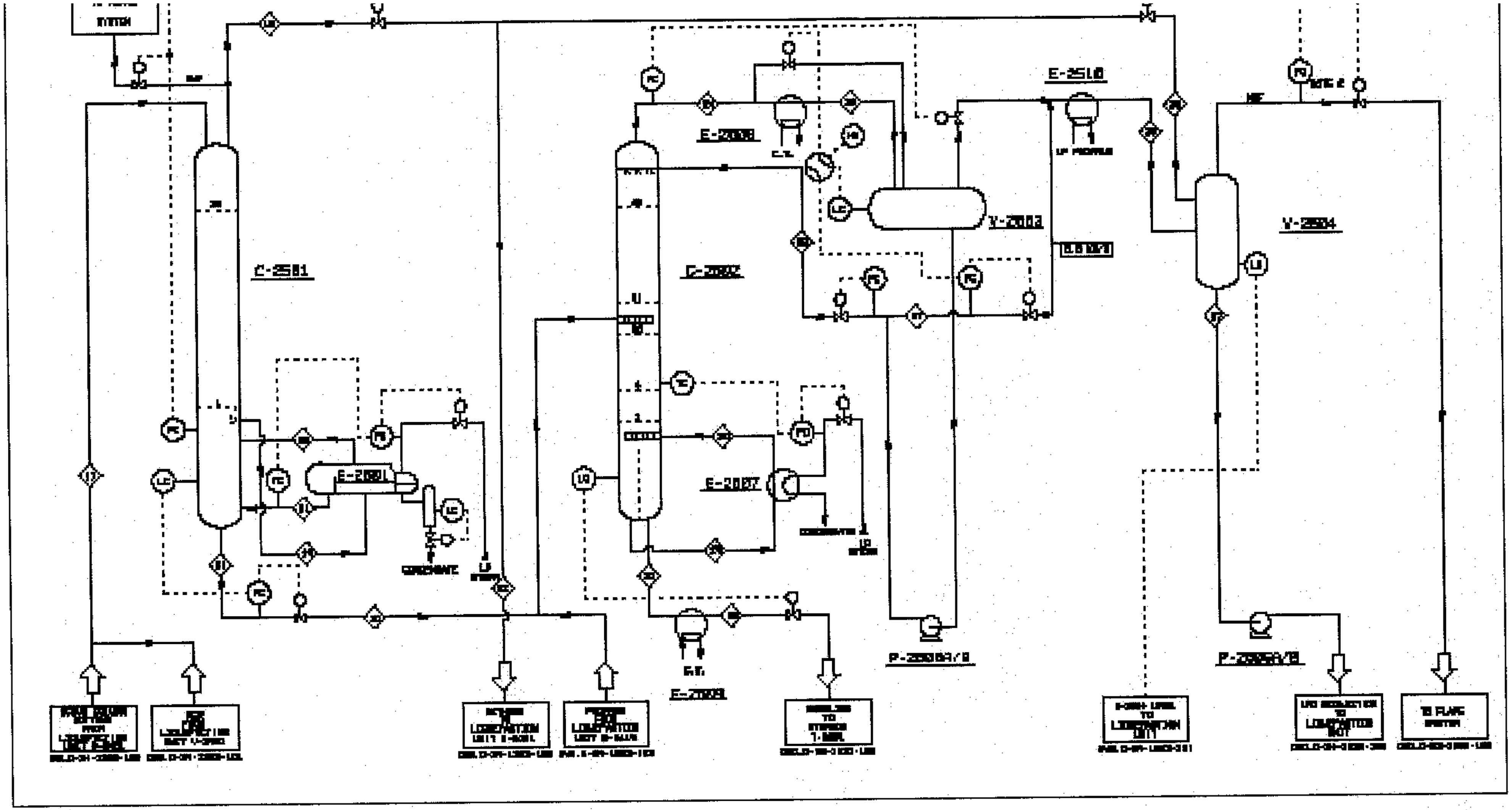


Figure C.1: Process Flow Diagram of Case Study (Established LNG Plant)

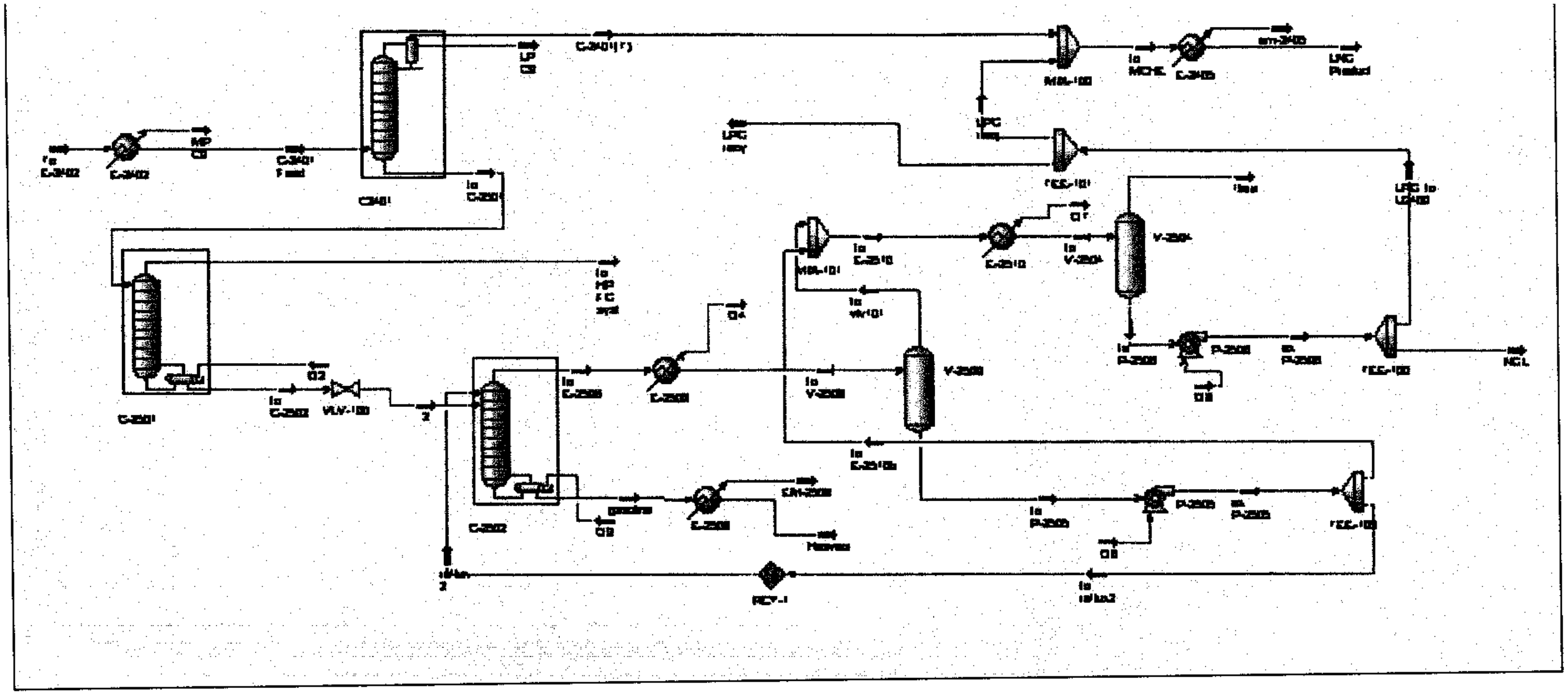


Figure C.2: HYSYS simulation (Steady –State) of Case Study

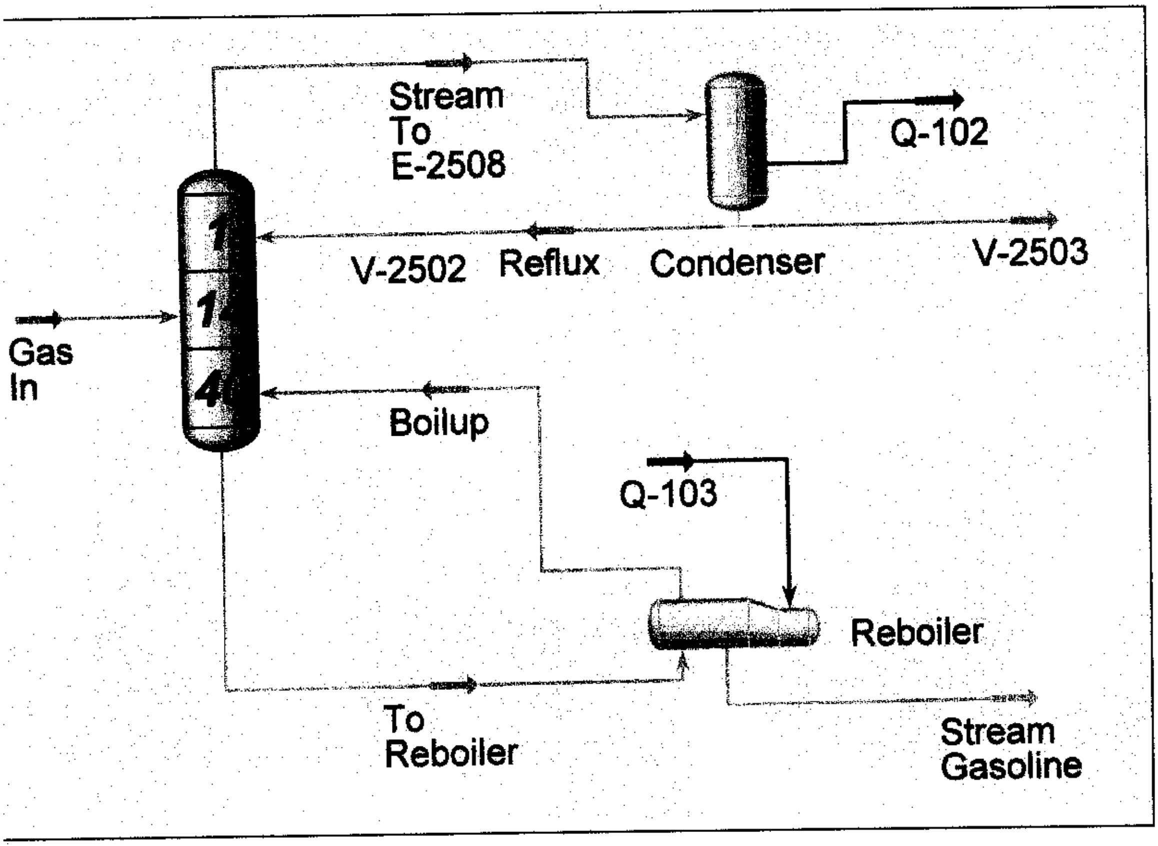
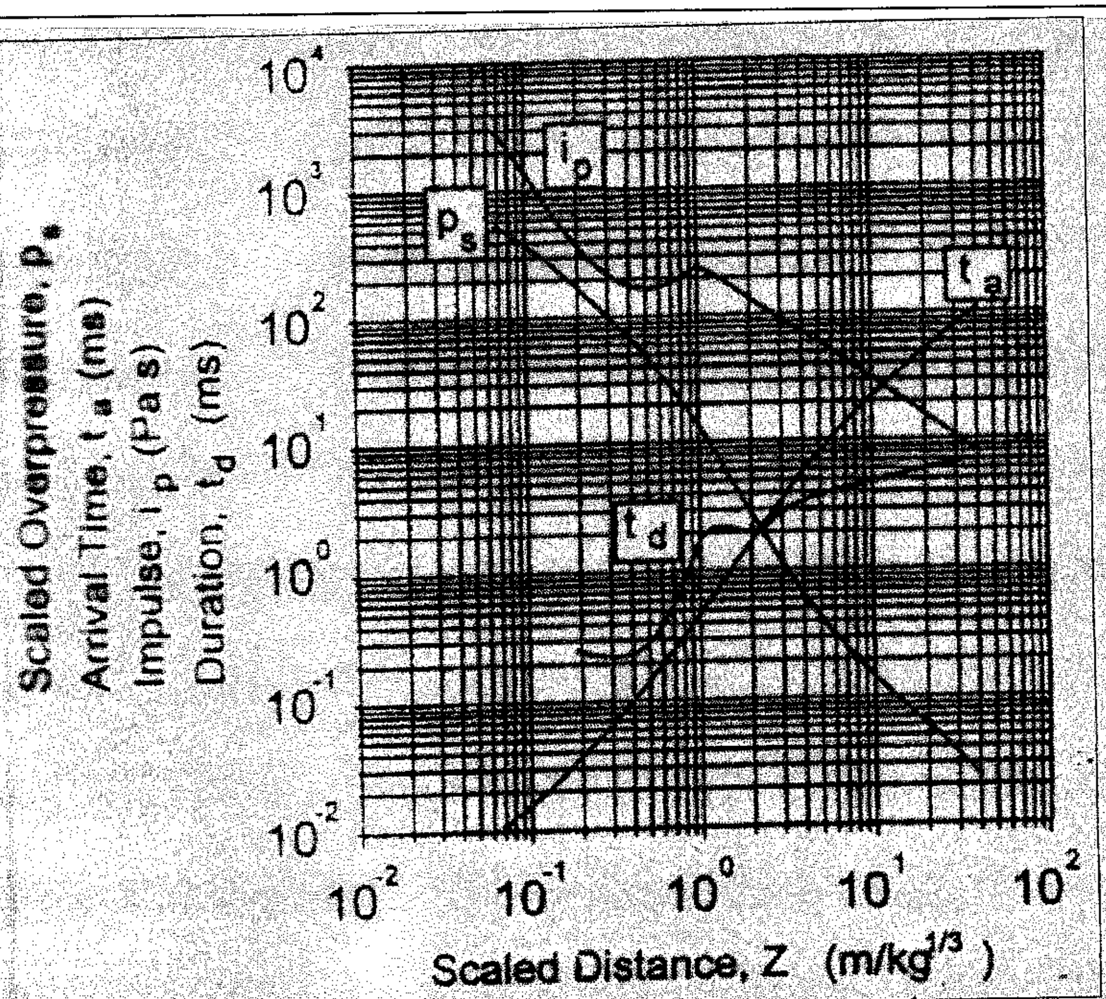


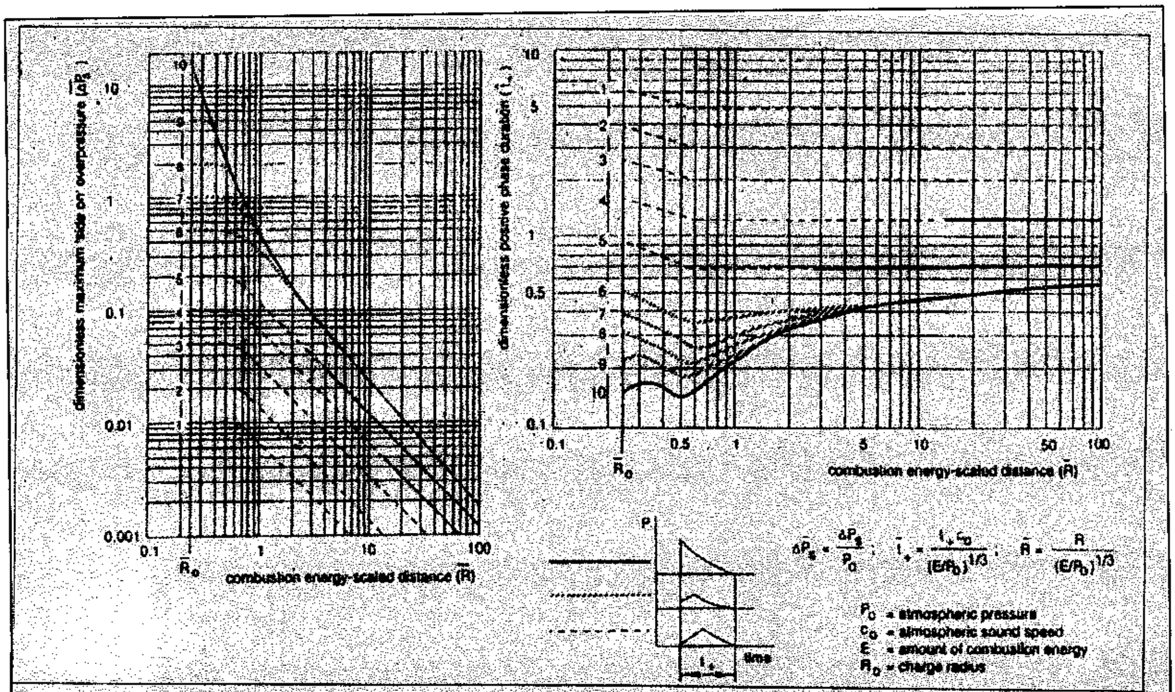
Figure C.3: Simulation of Stabilizer C-2502

APPENDIX D



Source: American Institute of Chemical Engineering, 2000

Figure D.1: Shock Wave Parameter for Spherical TNT Explosion on Surface at Sea Level (AiChe, 2000)



Source: American Institute of Chemical Engineer, 2000

Figure D.2: The Sachs Scale Side-On Overpressure and Positive Phase Duration are provided as A Function of the Sachs Scale Distance (AiChe, 2000)

Substance	MF	$\Delta H \times 10^{-3}$ (Btu/lb)	NFPA N_h	NFPA N_f	NFPA N_r	Flash point (°F)	Boiling point (°F)
Acetaldehyde	24	10.5	2	4	2	−36	69
Acetic acid	14	5.6	2	2	1	103	244
Acetone	16	12.3	1	3	0	−4	133
Acetylene	29	20.7	0	4	3	Gas	−118
Acrolein	29	11.8	4	3	3	−15	127
Ammonia	4	8.0	3	1	0	Gas	−28
Benzene	16	17.3	2	3	0	12	176
Butane	21	19.7	1	4	0	−76	31
n-Butene	21	19.5	1	4	0	Gas	21
Carbon monoxide	21	4.3	3	4	0	Gas	−313
Chlorine	1	0	4	0	0	Gas	−29
Chloroform	1	1.5	2	0	0	—	143
Cumene	16	18.0	2	3	1	96	306
Cyclohexane	16	18.7	1	3	0	−4	179
Dimethylamine	21	15.2	3	4	0	Gas	44
Ethane	21	20.4	1	4	0	Gas	−128
Ethanol	16	11.5	0	3	0	55	173
Ethanolamine	10	9.5	2	2	0	185	339
Ethylene	24	20.8	1	4	2	Gas	−155
Ethylene glycol	4	7.3	1	1	0	232	387
Formaldehyde	21	8	3	4	0	Gas	−6
Gasoline	16	18.8	1	3	0	−45	100–400
Glycerine	4	6.9	1	1	0	390	554
Hydrogen	21	51.6	0	4	0	Gas	−423
Isopropanol	16	13.1	1	3	0	53	181
Methane	21	21.5	1	4	0	Gas	−258
Methyl alcohol	16	8.6	1	3	0	52	147
Phenol	10	13.4	4	2	0	175	358
Propane	21	19.9	1	4	0	Gas	−44
Pyridine	16	5.9	2	3	0	68	240
Styrene	24	17.4	2	3	2	88	293
Toluene	16	17.4	2	3	0	40	232
Triethylamine	16	17.8	3	3	0	16	193
p-Xylene	16	17.6	2	3	0	77	279

Source: J. M. Ssantamaria Ramiro, 1990

Figure D.3: Lower Heat Combustion Data for Explosion Calculation.(J .M Ssantamaria Ramiro,1990)

APPENDIX E

Detail Description of Case Study, Stabilizer C-2502

The Stabilizer is a reboiled or refluxed column with vapor top product with 40 actual trays. The Stabilizer produces mainly two streams: a combined ethane/propane/butane overheated vapor stream and a pentane and heavier bottoms stream.

The overheated vapor stream form C-2505 flows to the Stabilizer Overheated Condenser, E-2508, where it is partially condensed using Cooling water. The two phase stream from E-2508 (flows to the Stabilizer Overheated Accumulator, V-2503, where the vapor and liquid are separated).

The liquid phase is pumped out of the accumulator by the stabilizer reflux pump, P-2505, and is returned to C-2502 as reflux. Liquid in excess of the reflux requirement of C-2502 is pumped into vapor stream from the accumulator, V-2503, up stream of the LPG condenser, E- 2510. The vapor phase from the accumulator flows into E-2510, where it is totally condensed using LP propane.

The pressure in C-2502 is normally maintained at about 6.5 barg by controlling the vapor stream out of V-2503 to the LPG condenser. P-2505A/B is protected by the minimum flow control system.

The liquid in the bottom of C-2502 flows to the Stabilizer Reboiler, E-2507, where it is partially vaporized by LLP steam. The mix streams in returned to the column under the bottom tray. The vapor passes back up the column stripping the lighter components from the liquid flowing down out the gasoline product cooler, E-2509, where it is cooled and sent to BCOT via gasoline metering in Unit 3200.

Source: Established LNG Plant in Malaysia